EMIT: EXPLICIT MODELING OF INTERACTIVE-ENGAGEMENT TECHNIQUES FOR PHYSICS GRADUATE TEACHING ASSISTANTS AND THE IMPACT ON INSTRUCTION AND STUDENT PERFORMANCE IN CALCULUS-BASED PHYSICS

A Dissertation

by

CATHY MARIOTTI EZRAILSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Curriculum & Instruction

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ABSTRACT

EMIT: Explicit Modeling of Interactive-Engagement Techniques for Physics Graduate Teaching Assistants and the Impact on Instruction and Student Performance in Calculus-based Physics. (December 2004)

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This study measures the effect of a model of explicit instruction (EMIT) on the: 1) physics graduate teaching assistants' adherence to reformed teaching methods, 2) impact of the instructional model on GTAs' beliefs about the nature of physics and physics problem solving and 3) undergraduate physics students' understanding and performance in an introductory calculus-based physics course. Methods included explicit modeling for the treatment group GTAs of the Reformed Teaching Observation Protocol (RTOP) and assessment of treatment and control GTAs and their students throughout the semester. Students' understanding was measured using the Force Concept Inventory (FCI) and Flash-mediated Force and Motion Concept Inventory (FM^2CA). Students were surveyed about performance of GTAs using the Student Survey (SS). Results indicated changes were tied to individual GTAs' beliefs about the nature of physics. Student conceptual understanding reflected a two-fold Hake gain compared to the control group. General application of the EMIT model presupposes explicit instruction of the model for GTAs.

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CHAPTER I

INTRODUCTION

> One of my major preoccupations is the approximation between what I say and what I do, between what I seem to be and what I am actually becoming.
>
> − Paulo Freire, *Pedagogy of Freedom*

During the last two decades, physics education researchers have begun to approach the problem of student conceptual change by conducting detailed systematic studies on the teaching and learning of physics (McDermott, 1984; Hestenes, 1996; Hake, 1998; Beichner, 2004). Redish, Saul & Steinberg (1998) examined the goals of introductory college physics instruction and what students actually are able to retain and use, after taking only one class. They concluded that there is a gap between what is taught and what students -- even those who continue in specific fields of physics -- need.

Student difficulty with physics concepts and learning had begun to be studied from a new perspective within the physics community when the physicist Robert Karplus turned his attention to learning theory and defined his “learning cycle” (Fuller, 2002). Among the most far-reaching and innovative efforts in this direction were the Harvard Project Physics program, published in 1970, and its predecessor -- the high school physics course designed by the Physical Science Study Committee (PSSC) in 1957. The early research in this area focused mainly on student learning, difficulty with mathematics and with the perception

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This dissertation follows the style of *Educational Researcher.*

that physics was a difficult subject beyond the comprehension of most people (Gollub, Bertenthal, Labov & Curtis, 2002). *Center for Education* of the National Academy in *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools: Report of the Content Panel for Physics* (2002) recommends that a physics curriculum should focus more on conceptual understanding and less on mathematical manipulation.

Traditionally, at large American universities, physics graduate teaching assistants (GTAs) assume the responsibility for fifty per cent of the instructional time in a typical introductory physics course. The assumptions made and expectations for the teaching and performance of these teacher-students are not always made clear. The education of physics graduate students has become the subject of increasing attention and concern in the physics community (Jossem, 1999). And, although there are some notable and excellent instructional programs for GTAs at many universities (The University of Minnesota, Arizona State University, North Carolina State University, Ohio State University and the University of Maryland are examples) few or limited opportunities exist for graduate teaching assistants to learn instructional methods for effective teaching. The bulk of instructional training for GTAs is learned on the job.

Of major importance in any program of planned pedagogical program for GTAs is the growing body of serious research in physics education, the results of which need to be incorporated into the curriculum underpinning GTA instruction.

Effective instruction relies on an impeccable and explicit communication -- from physics professor to graduate teaching assistant to undergraduate physics student -- the expectations and instructional goals for the course must be clear for all participants. Tobias, Chubin and Aylesworth (1995), propose new ways to prepare undergraduate and graduate majors in science. The Boyer Report suggests that course improvement could be accomplished if graduate teaching assistants were instructed specifically in teaching methods, as well as in other areas of their preparation (Boyer, 2001). Some physics graduate teaching assistant training is supported by written reference materials that do a good job of emphasizing methods that many physics education researchers refer to as *reformed teaching* (Heller, Keith & Anderson, 1992; Jossem, 1999; Beichner, 2004). Often lacking, however, are formal instructional programs specifically designed for physics teaching assistants based on decades of research and pedagogical development. At Stanford University, the physics TA handbook includes a description of teaching expectations as follows:

> The TA is diplomatic, helping students relate to physics by providing contexts for new concepts and enabling students' self-discovery of fundamental principles. The TA role traditionally draws upon many resources including worked examples, cooperative problem solving, investigative laboratory exercises, and personal discussion (*Stanford Graduate Teaching Handbook*, 1999).

This statement is followed by an encouragement to the "interested physics teaching assistant" to go online to visit the physics teaching manual. No formal instructional program is offered nor are there definitions of the terms *cooperative problem solving* or *contexts for new concepts*. This training program is typical of physics TA training offerings in many research one universities. Notable exceptions include fine programs at the University of Minnesota, Arizona State and the University of Maryland, to name a few examples. Students enter introductory physics with a set of beliefs about what they do and do not know about physics (Hammer & Elby, 2002) This initial understanding has been shown to directly impact thinking about and conceptualizing fundamental principles in physics (Roschelle, 1995).

Graduate teaching assistants also have formulated a set of beliefs about the nature of physics and physics problem solving arising from their experiences with physics before they begin to teach it to introductory students (Redish, 1999). Several physics education researchers have suggested core requirements that are needed in order for any reform to have a lasting impact. Among these, according to Elby (1999) the fact that so many excellent physics courses fail to initiate significant change in beliefs about the nature of physics, even courses incorporating some of the results of physics education research, suggests that isolated instances of epistemologically-focused curriculum aren't enough. Every aspect of a course must be reformed. This indicates that an instructor's (or GTAs) understanding of the nature of physics must go beyond a mere willingness to implement curricular elements. No partial adoption of reformed curricular elements can lead to lasting change (Elby, 1999).

The classroom atmosphere created by an instructor with its interactions between students can facilitate metacognition in students. The Minnesota Model (Heller et al., 1992) encourages continuous interaction between the instructor and student as well as student-to-student, working in well-defined roles and interactive opportunities during problem solving. In his *Guide to Introductory Physics Teaching,* Arons (1990) stressed the importance of the use of explicit language in construction of knowledge and in acquiring meaning and in achieving understanding. Hake (1998) also characterizes that physics reforms, which include an “Arons-advocated method of science education,” are interactive concept-building reforms, abandoning the standard passive student lecture and embracing a more student-focused approach.

The content, articulation and explicit nature of the graduate teaching assistants’ pedagogical instruction, the supervision of the graduate teaching assistants and clear expectations communicated to the student have been found to impact quality of instruction (Bao & Lee, 2001). What has not been firmly established is whether graduate teaching assistants, instructed through explicit modeling of the interactive problem-solving techniques shown by decades of physics education research to have positive impact on student learning, can successfully apply these methods and produce positive changes in: 1) their adherence to methods of reformed teaching, 2) a change in their views about the nature of physics and physics teaching and 2) their introductory physics students' conceptual understanding of fundamental principles. Such a model has been developed in this study.

Statement of the Problem

Can the application of Explicitly Modeled Interactive-engagement Techniques (EMIT), an articulated instructional model for physics graduate teaching assistants incorporating aspects of a modified Cognitive Apprenticeship instructional model, have a positive impact on GTA understanding of the nature of physics and physics teaching and, when applied to cooperative group problem-solving, enhance undergraduate students' perceptions and performance in calculus-based physics? Further, will this pedagogical instruction, designed to be specifically responsive to the needs of the physics graduate student by modeling the techniques expected as GTAs teach during recitation, also translate into a maturation of GTA understanding about the nature of physics and physics understanding?

Research Questions

1. To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?
2. What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?

3. What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem-solving process?

Theoretical Framework

Giere (1997) contends that underpinning any scientific model is a myriad of perspectives that take shape in the form of representations and give a fuller (although not entirely complete) picture of the model. Additionally, teaching and learning expectations cannot be satisfied if steps to fulfilling them is not made clear (Schoenfeld, 1985). Further, Minstrell (2001) and others have found that naïve conceptions if not made visible and directly addressed have been shown to impede the understanding of new concepts. Naïve conceptions can exist side by side with mature understanding of ideas even in the physics professorate has been shown by Henderson & Dancy (2004).

Reformed physics instruction that incorporates multiple methods and techniques has been shown in several studies to positively impact student learning in introductory classes (Dykstra, Boyle, & Monarch, 1992); Cummings, Laws, Redish & Cooney, 2004). The Arizona Collaborative for Excellence in the Preparation of Teachers – (ACEPT) -- recommends that reformed instruction include: 1) content knowledge in two domains (propositional and procedural), 2) lesson design and implementation that respects students' prior learning, and 3) interactions in which students actively participate with each other and the instructor (Piburn, Sawada, Falconer, Turley, Benford, & Bloom, 2000). The implementation model used in this study was derived in part from the definitions of reformed teaching coupled with the addition of a model based on Cognitive Apprenticeship (Collins, Brown & Holum, 1991) and based on the application of multiple representations to cooperative group problem solving suggested by Giere (1997).

Reformed Physics Teaching and the Synthesis of the EMIT Model

The EMIT model was synthesized from the body of research of studies on reformed physics teaching and was formulated after a recitation pilot study in two sections of the honors introductory calculus-base physics reform during the Spring Semester, 2003. As an alternative to the teacher-directed, lecture-focused, traditional method, a model of interactive-engagement methodology (EMIT) was formulated. EMIT is explicitly designed to be modeled for graduate teaching assistants during their instruction and subsequently employed by them during recitation. This model defines the desired climate and behavior that fosters “reformed” physics teaching. Table 1 summarizes the elements of reformed physics instruction from which the EMIT model was derived and then applied by graduate teaching assistants during instruction of introductory physics students.

A separate and subsequent *Visual Physics* pilot study, incorporating lab and technical writing as well as incorporating the EMIT model, was performed under the direction of Dr. Peter McIntyre during the Fall Semester, 2003 in the Physics Department at Texas A&M University. Impetus for the *Visual Physics* pilot study was a need to respond to the failure of the present introductory calculus-based physics course to respond to the changing needs of departments of engineering, physics and of the professors and students alike. Within the larger auspices of the course reform effort, the graduate teaching assistant instruction and recitation reform model (EMIT) was the focus for this study. See Table 2 for further explanation of the elements of this model.

Table 1 *Comparing Traditional to Reformed Physics Instruction*

Domain Addressed	**Traditional (Direct) Instruction***	**Reformed (Inquiry-oriented) Instruction****
I. Lesson Design and Implementation	Instructor sets objectives and reviews relevant past learning. The content is derived from explicit standards revealed to the student by the instructor and text.	Student-centered instruction that respects students' prior learning and creates an environment that engages students interactively.
II. Content (Propositional Knowledge)	The lesson is instructor prompted. Use of "advanced organizers, or other framework to direct the organization by the instructor.	The instructor demonstrates an "expert" grasp of content while exploring applications to the real world, interdisciplinary contexts and phenomena.
III. Content (Procedural Knowledge)	Derived from Hunter's Model, the Seven-step Checklist: 1) Objectives, 2) standards, 3) anticipatory set, 4) teaching, 5) guided practice, 6) closure and 7) independent practice. Examples and analogies are used. Re-teaching is done if students do not show understanding. Instructor-directed questioning strategies are used. "Anticipatory set" or prompt begins a lesson.	The instructor employs scientific reasoning; interactive-engagement pedagogy and guides student learning, encouraging students to use a variety of representations and to characterize concepts. Students make and test predictions, hypotheses, estimates, and conjectures. Students are actively engaged in thought provoking activities and engage in intellectual dialogue, debate, negotiation and interpretation of concepts.
IV. Classroom Culture (Communicative Interactions).	Instructor provides information needed for students to gain the knowledge or skill through lecture, film, tape, video, etc. After presentation, the instructor uses the material as examples of what is expected. Students use drill and practice methods. Instructor-centered and directed Activities are used to demonstrate grasp of new learning, under instructor direction.	The instructor engages in several alternative strategies to re-focus students through encouraging divergent modes of thinking and induction. Student questions and comments shape and direct interactions with the instructor and guide student thinking. The instructor maintains a climate of respect and expectation for student contributions.
V. Classroom Culture (Student-Instructor Relationships)	The instructor determines the level of mastery. The instructor asks if there are any questions. Deduction is used in a top down method. Focus is on the lesson. Lock step procedure where all students proceed at same pace. Closure is done at the end of each lesson to consolidate points, organize learning and reinforce points.	The instructor encourages interactions in which students actively participate. Students take primary and active responsibility for their own learning. The instructor is patient – listening, observing and engaging with appropriate "wait time." After student questions. The instructor acts as a resource and guide, validating student efforts.

*Derived from the Madeline Hunter example of Direct Instruction ** Reformed Teaching Model, delineated by Piburn & Sawada (2001) and MacIsaac & Falconer (2002).

The EMIT model is a heuristic that places the GTA into the role of content expert and cognitive coach who: 1) shares expertise in physics content and concepts with the novice physics student, 2) interacts with cooperative student groups during problem-solving and 3) applies progressively fading scaffolds (support and guidance) during model-building (Brown & Clement, 1999). Conceptual understanding and problem-solving ability are enhanced as students work in interactive teams of three, with pre-determined roles, building models to solve concept-rich problems, with the "expert" graduate teaching assistant circulating to "coach," support and guide through analytical road-blocks when they occur (Finkel & Monk, 1983; Halloun & Hestenes, 1985; Heller et al., 1992; Heller & Hollabaugh, 1992).

In Figure 1, the process of using multiple representations in constructing models of the real world is a cyclic enterprise, employed by learners during the process of learning new concepts (Giere, 1999, Nola, 2002). In the *Visual Physics* recitation reform, physics students approached learning of fundamental principles and their specific applications by using this process of model building involving context-rich, multi-concept problem-solving scenarios.

Table 2 *EMIT: Explicit Model of Interactive-Engagement Techniques Designed for Physics Graduate Teaching Assistants' Instruction*

Domain Addressed	Instructional Element Used in EMIT Model	GTA/Student Actions
I. Lesson Design and Implementation	• Cooperative Group Problem-solving (Heller & Heller, 1995). • Student explorations/questions preceded instruction	Students' prior learning was respected. Student questions and comments shaped interactions with graduate teaching assistants. Students were encouraged to use a variety of representations to characterize physics concepts. Students worked cooperatively in groups with predefined roles to solve content-rich problems.
II. Content (Propositional Knowledge)	• Socratic dialogs between student and GTA (Hake, 1998). • Careful Elicitation Questioning – student to student and student to GTA (Minstrell & Kraus, 2001). • Use of Multiple representations (Van Heuvelen, 1997; Giere, 1997).	Graduate teaching assistants engaged in Socratic questioning strategies in order to re-focus student groups. GTAs employed scientific reasoning and interactive-engagement pedagogy. Their methods addressed the fundamental concepts of physics, promoted coherent understanding across topics and during problem solution. The GTAs as content experts, actively engaged in thought provoking opportunities and on-the-spot assessment of student difficulty. Students were guided as they began to move from novice to expert-like understanding of the fundamental concepts of physics.
III. Content (Procedural Knowledge)	• Cognitive Coaching Methods (See Figure 2). • Just-in-Time intervention (Novak, 1999). • Debate and Negotiation • Giere's Scientific Reasoning Methods of Abstraction and Concretization (See Figure 1). • Student-GTA roles "reciprocate" in a process similar to the "reciprocal teaching" model (Palincsar & Brown,	The GTAs monitored the formation of and operation of the cooperative student groups that engaged in intellectual dialogue, debate, negotiation, interpretation of concepts, formulating solutions. The GTA, using cognitive coaching methods in guiding student learning, encouraged and validated student ideas through hands-on application of basic principles learned in lecture and homework. Students were encouraged to engage in the process of abstraction (simplification of the real world) and concretization (re-application of concepts to the real world). The graduate teaching assistants encouraged students to make and test predictions, hypotheses, estimates, and conjectures during problem solution, capitalizing on "Just-in-Time" opportunities to intervene and guide student thinking.
IV. Classroom Culture (Communicative Interactions).	• Solution Model-building during context-rich problem scenarios • Student-centered learning environment (Bransford, et al., 2000).	The graduate teaching assistants' questions encouraged divergent modes of thinking and student model-building through induction while maintaining a climate of respect and expectation for student contributions. GTAs encouraged problem-solving scenarios in which students actively participated.
V. Classroom Culture (Student-Instructor Relationships)	• Student-centered lesson design encouraged risk-taking and student empowerment. • GTA acted as "listener and guide," (Collins, et al., 1989).	Students took primary and active responsibility for their own learning. The graduate teaching assistant was patient – listening, observing and using appropriate "wait time" as students cooperatively solve problems. The graduate teaching assistant acted as a resource and guide students, validating student efforts and listening to student comments.

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Students work cooperatively in small groups to create multiple representations of aspects of the problem, creating what Giere (1997) calls a “family of models.’ Negotiating proceeds as students interact with one another and with the GTA to generate hypotheses and generalizations for the models constructed, using their models to construct meaning and conceptual understanding. Also important in the process is relating what is learned to the real world, re-checking that the model is still applicable or modifying it until it fits.

Building models, according to Giere (1997), depends on the intentions behind the theory that underpins the model and the “complexion” of the intended audience. Giere further states that it is a *family of models* and a *set of theoretical hypotheses* that select for relevant occurrences in the real world to support the theory. What cements everything is the ability of the underlying models to help explain and understand the phenomena under study. In then applying the understanding of these models to instruction, correspondence between our model with the real world and the evidence that the model works is integral to its usefulness (Giere, 1997, 1999). In Chapter III the application of this framework to the EMIT model developed for this study will be discussed.

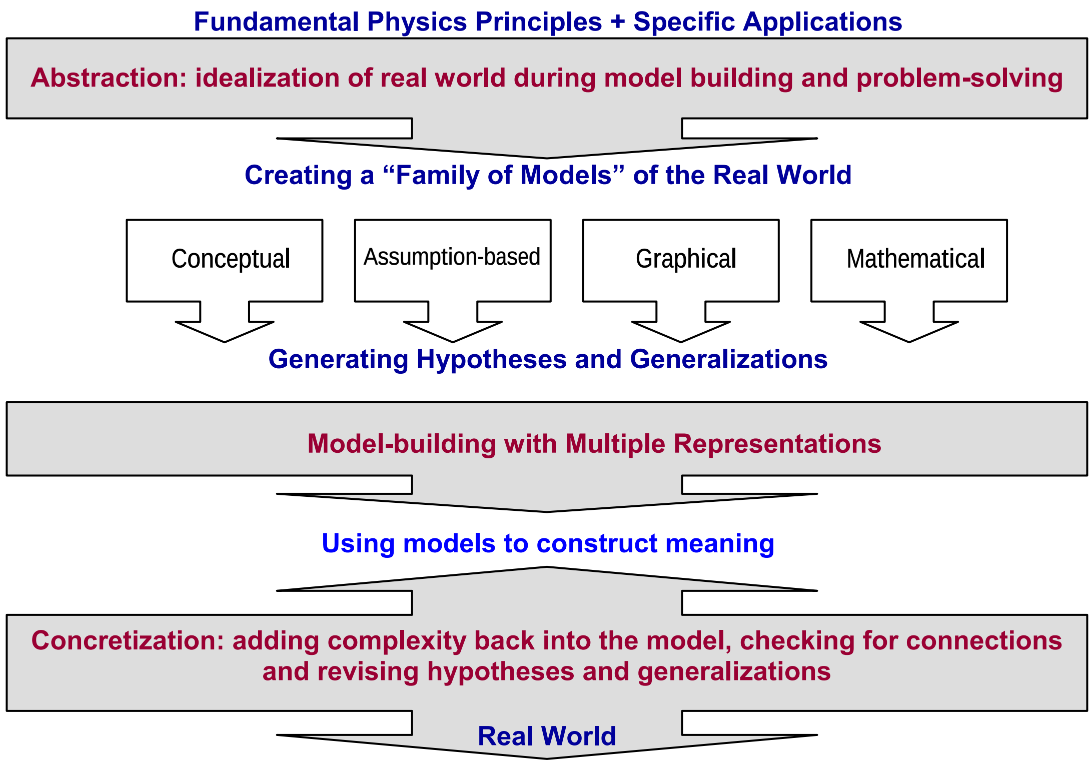


Figure 1 Multiple Representations and the Process of Model-building (Giere, 1999, Nola, 2002).

In this study, the theoretical framework blends the perspective on models as only partial representations of the real world that must be assembled in order for concepts to be understood and with the application of a modified Cognitive Apprenticeship model for instruction (Giere, 1997; Nola, 2002; Collins, Brown & Newman, 1989; Brown & Duguid, 1993). The concept of the Cognitive Apprenticeship Model directs that the students work in teams on problem solving with guidance and support from the graduate teaching assistant. Cognitive apprenticeships are representative of Vygotsky’s "zones of proximal development" in which student tasks are made more difficult than students can manage alone, requiring a cooperative teamwork and graduate assistant (expert) intervention so the student (novice) moves into a community of expert practice. In Figure 2 an instructional method shown was designed to give students the opportunity to observe, engage in, invent, and/or discover expert strategies in context is delineated (Collins, Brown, & Holum, 1991).

In Figure 2, the researcher explicitly models the instructional behaviors expected of the graduate teaching assistants, coaching, guiding and questioning, while students engage in cooperative group problem-solving in introductory physics. The EMIT model is applied to graduate teaching assistant pedagogical instruction and later is used by the graduate student in creating a problem “scenario” that challenges students to solve a multi-concept problem with a real world context. GTAs coached students to engage in collaborative interactions with predefined roles – that of skeptic, manager and recorder. The process of learning the EMIT model, with the researcher coaching and scaffolding provided the graduate teaching assistants with the skills and strategies that they would need to instruct students interactively during recitation. This allowed the graduate teaching assistant to acquire the skills needed in order to guide students through successfully completing the problem-solving and model-building scenarios. “Wait time” and “Just-in-Time” intervention were also skills built into the model to enable GTAs to help students in the process of solution model building through abstractions (representations) and concretization (adding back in real world complexity).

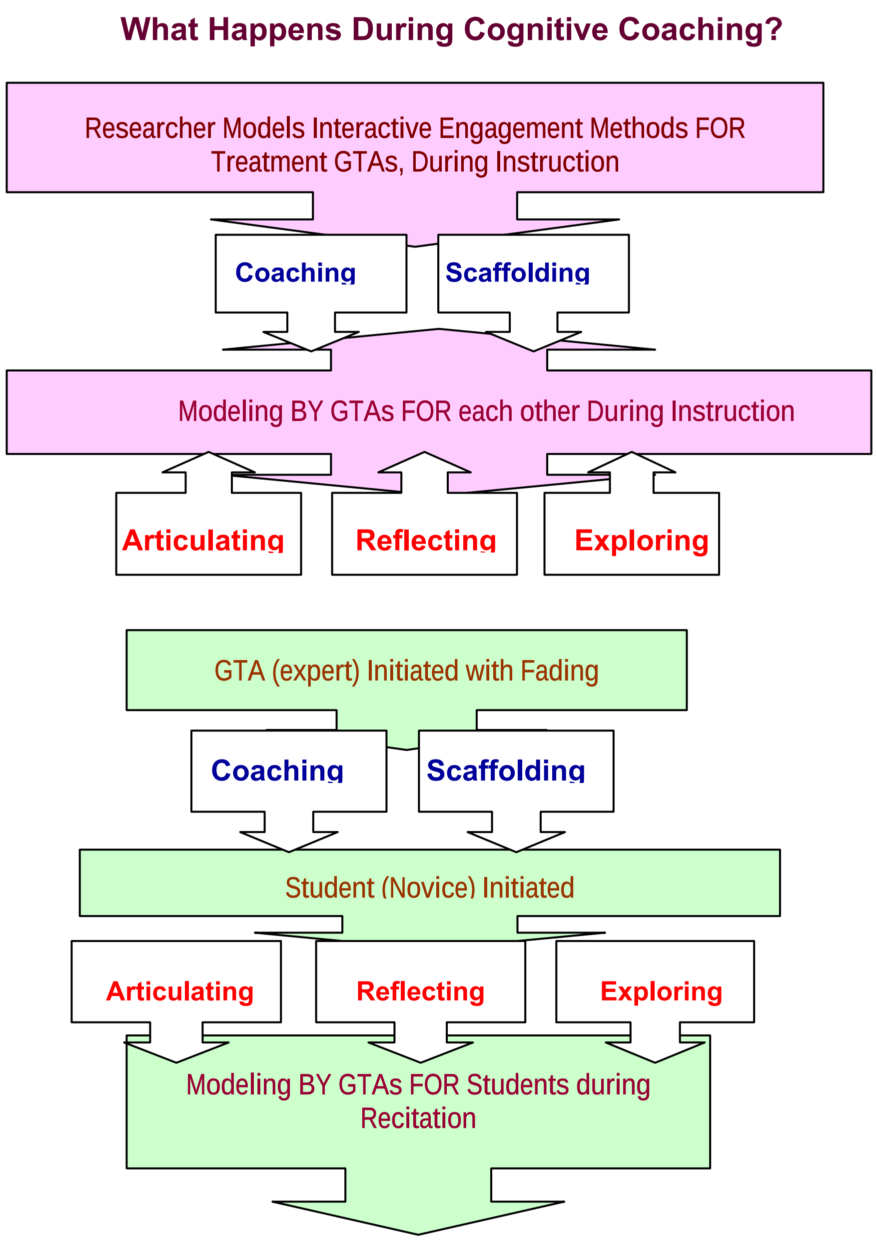


Figure 2 Modified Cognitive Apprenticeship Model

Students then were engaged in the formation of foundational concepts through a model of “authentic” practice much like scientists do in forming theory. Both the graduate teaching assistants and students were encouraged to articulate the construction of models, revealing their thinking and making the process of problem solving explicit.

Important Terminology

Interactive Engagement

The development of conceptual understanding of basic physics content and process includes active communication between the graduate teaching assistant and student, as well as between students, encouraging participation through constructing of solutions (model-building). This occurs when students are engaged in the context-rich group learning scenarios. The negotiation process helps students to become explicitly aware of their own learning (meta-cognition) and actively involves them in building new concepts from prior knowledge, folding in what is newly understood. Students are given an opportunity to evaluate and negotiate, as they are interactively guided in this process by the graduate teaching assistants.

Cognitive Apprenticeship Model

In the Cognitive Apprenticeship model (Collins, et al., 1989), the apprentice (student) observes the expert (graduate teaching assistant) model the different parts of a task (physics problem-solving scenario). The process of “cognitive coaching” involves a process by which the graduate teaching assistant acts as guide, scaffolding the lesson, fading as students gain in expertise. Students are engaged in 1) articulation, encouraging them to verbalize conceptual change and make explicit their thinking; 2) reflection, during which students review their performance, interacting, discussing and questioning and 3) exploration, during which students offer alternative explanations, building models and negotiating problem solutions. During cognitive coaching, the expert uses the process of *scaffolding,* a bridging techniques that requires more support initially with fading of support as students become more proficient.

Novice

A novice learner's experience is in large measure determined by situations encountered during the problem task. Only a small fraction of that task can be understood at once (Giere, 1999; Elby, 1999). The student, when participating in cooperative group problem solving, has the ability to confer with other novices and the graduate teaching assistant (expert) as confidence and skill at complex solutions are constructed. During the transformation from novice to expert, another type of change occurs -- the process of acculturation. The novice actually participates in the world of expert and the model of interactive-engagement instruction enables novices to acquire the required knowledge (often tacit) in ways that facilitate their entry into the culture of expertise (Epstein, 1995).

Expert

Expert thinkers can learn to perform difficult tasks well because they can zero in on key points in decision-making and can extract the important kernel of knowledge from them. The expert is able to explain thinking and calculating strategies (Larkin, 1983a; Larkin, McDermott, Simon & Simon, 1980). The expert also provides initial steps for using a particular strategy, helping students to decide when each is appropriate. Interaction on the part of expert and novice is another prominent aspect of cognitive coaching. In the "scaffolded" instruction technique, instructors and students take turns leading dialogs about the problem, predicting, questioning, clarifying, summarizing, and self-appraising (Collins, et al., 1991). Experts are trained to focus on: 1) common conceptions held by students; 2) assessment of student performance, adjusting "scaffolding" needed; and 3) negotiation and interaction. Experts are most effective if they have information about students' prior conceptions and are observing the strategies that students use. Novices learn from the experts as they guide and fade the specificity of the instruction.

The Nature of Science and the Nature of Physics

Loving's (1991) *Scientific Theory Profile* shows the breadth of philosophical views on the nature of science and illuminates the lack of agreement among philosophers (as is the case with scientists themselves) about the nature of science.

According to Cobern and Loving (2001) understanding the nature of science means understanding that:

- Science is an explanatory system used to account for natural phenomena that ideally must be objectively and empirically testable.
- Science is about natural phenomena
- The explanations that science offers are naturalistic and material
- Science explanations are empirically testable against natural phenomena or against other scientific explanations of natural phenomena
- Science is an explanatory system—seeking to explain how things work, woven into a system of theoretical thought
- Science presupposes the possibility of knowledge about nature
- Science presupposes that there is order in nature
- Science presupposes causation in nature

Driver, Leach, Millar & Scott (2000) define science as knowledge about the real world as well as a set of processes through which new discoveries are made.

The nature of physics is more than the process of doing physics must also include the history, philosophy and turn of mind of those who undertake the practice of and thinking about physics in its myriad forms. It is not only a way of thinking about the world through the “lens of physics” but also a way of thinking about it in context of science as a whole enterprise as well as connected to other disciplines. The process and methods of teaching physics reflect the beliefs, understandings and attitudes towards science and scientific endeavor by the instructor.

Models

Models help us to visualize a problem and break it down into discrete, manageable pieces for study. Models encompass a breadth of communication vehicles, such as images, text, physical models and mental constructs. The words that are used to describe the model and the role of imagery in creating them are vital to a model's usefulness in description (Sadowski & Paivio, 2001).

Models are by their very nature incomplete and limited and are representations of an idea or phenomenon as the basis of new ways of thinking about the real world (Gobert & Buckley, 2000). Models usually evolve and are modified, as new scientific evidence is uncovered. Modification of the underlying theories as well as the construction of new theories may result.

Mental Models

Mental Models are personal, internal representations of parts of a system (Johnson-Laird, 1983). Mental models can be a consequence of interaction with the real world and based on folding observation and new evidence into prior experience and prior models. Scientists sometimes use the term "mental model" as a synonym for "mental representation." *Expressed models* are the external representations by the learner and are expressed through action, speech, and the written word and by other means (Gobert & Buckley, 2000). According to Gilbert & Boulter (2000), mental models are a universal way of thinking and expressed models are an important and universal component of communication. In this study, during problem solving, students express a model for problem solution, based on a complex physics scenario. Students can use multiple representations – conceptual, assumption-based, graphical, and mathematical -- as a basis for constructing meaning of concepts as they engage in model building and problem-solving.

Mathematical models are symbolic ways to describe a physical relationship between the real world and an explanation based on an observed relationship between concepts. A mathematical model may be a set of equations that describes a conceptual model in mathematical terms where variables are used to discover new relationships and represent them in equations. A mathematical model is usually an abstraction of a real-world problem into a mathematical problem.

Modeling

Modeling is the essence of thinking and working scientifically. Yet, students often default to simple explanation or to mathematical solutions when solving problems. This prevents the student from gaining insight into the concepts the models represent. Pederson and Lui (2003) suggest that students transfer strategies during problem-based learning that they then apply to a novel situation -- a process that moves the novice student to a more expert practice. Hestenes (1996) delineates not only the process that students engage in during acquiring “transferable skills,” but also how the process that the instructor engages in can make the structure of knowledge more explicit for students.

There are several key concepts common to model-based reasoning (Magnani, Nersessian & Pizzi, 2002).

1) The definition of `model' encompasses both internal and external representations.
2) These models are defined also as interpretations of “target physical systems” and their processes, phenomena, and situations.
3) Models are retrieved or constructed on the basis of “potentially satisfying salient constraints” of the target area.

In the modeling process, various forms of abstraction are used. The evaluation and adaptation processes also take place in light of “structural, causal, and/or functional constraints.” Model simulations can be used to produce new states and enable evaluation of behaviors and other factors (Nersessian, 1999). According to Nersessian, model-based reasoning is “generative of conceptual change in science” and requires a revisiting of the understandings of the meaning of *concepts*, *conceptual structures*, *conceptual change*, and *reasoning*. Model-based reasoning applied in this study during graduate teaching assistant instruction and by the GTAs during recitation is based on Giere’s “perspectival” model, encouraging an evaluation of the degree to which a model fits some aspect(s) of the real world (Giere 1997, p. 35).

In order to develop a deep understanding of science based upon an inside knowledge of what scientists really are doing, Giere (1997) argues that it is important to understand how scientists construct models, which are limited representations of aspects of the real world. It takes a “family” of models to begin to gain conceptual understanding and correspondence with the real world. Taking theory into practice through a process that is more akin to the process scientists use, allows students to begin not only to demonstrate, but also to internalize their learning of physics concepts.

Cooperative Group Problem Solving

In the case of cooperative group problem solving and through interactions with online simulations, students negotiate meaning through constructing models and then generalizing to novel situations (Reif, et al., 1982; Schoenfeld (1985); Van Heuvelen, 1997). Just as problem-based learning encourages cooperative group methods, teamwork and negotiation between students, so too does the EMIT model encourage similar interactions between students and graduate teaching assistants. This process occurs during problem solving in recitation, facilitating model building as students engage in the transfer learning to novel situations. Many studies have shown that this teaching methodology not only enhances students’ learning of fundamental physics concepts, but also has the potential to 1) increase their ability to solve real world problems and 2) to increase motivation for learning (Roschelle, 1991; Heller, et al., 1992).

Computer Modeling and Simulations

There are many different types of computer simulations, but many share the common goal to generate representative scenarios for a model in which a complete picture of the model would otherwise be impossible. In this study, simulations were one method used to get at student thinking during problem-solving (Ezrailson, Allen & Loving, 2004). This process encourages modeling solutions by students "…Modeling helps students to understand the use of strategies within a context that makes them meaningful, and then provides them with the opportunity to apply these strategies to a complex task in which they are engaged" (Pedersen & Liu, 2003, p 28). During model building, students reveal relationships and establish patterns about how objects behave and interact .

Summary

The impetus for this study is a half-century of research into how introductory calculus-based physics students can best learn physics. Interactive-engagement methods, used in the process of solving real world complex problems have been shown to enhance students' conceptual understanding of physics concepts (Larkin, 1983b). Conceptual understanding and problem-solving ability have been shown to improve as students work in small teams with an "expert" assistant, circulating to "coach," support and guide through analytical road-blocks when they occur (Collins, et al., 1991). Minstrell (2001) characterizes the process of interaction with students during concept formation and model building as a "hands in the pocket" process for the teacher.

In other words, eliciting and listening to student characterization of their conceptions and addressing them during instruction are an essential part of the process an effective instructor should model.

There needs to be an understanding and recognition that effective instruction does not naturally follow when a graduate student gains a teaching assignment in physics. Teaching is a skill to be learned with guidance and practice. Expert knowledge of content does not automatically impart skill of communicating that expertise to others. Effective and explicit instruction, using the EMIT model, that incorporates the exemplary methods outlined in this study and others, depends upon the pedagogical preparation, coaching and mentoring of the physics graduate teaching assistants. GTAs must be prepared to aptly apply the cognitive coaching methods that incorporate context-rich problem solving, model building and group interactions and be guided through the process by the same model with which they were instructed.

Several decades of research into how people learn (e.g. Minstrell, 1984; Mestre, Dufresne, Gerace, Hardiman & Tauger, 1993; Redish 1994; Roschelle, 1995; Pellegrino & Bransford, 2000) has contributed to the application of research on cognitive processes to science instruction. Chapter II will look at those processes and other research and illustrate how they underpin this study and the EMIT model.

CHAPTER II

LITERATURE REVIEW

> Extraordinariness is most likely to emerge if aspiring individuals are exposed to extraordinary models; ponder the lessons embodied in those models; and have the opportunity to enact critical practices in a relatively protected setting.
>
> ─ Howard Gardner, *Extraordinary Minds*

Research Questions

1. To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?
2. What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?
3. What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Introduction

The EMIT model for the reform of recitation in *Visual Physics* was derived in part from the results of a compendium of introductory physics reform efforts whose research has been published over the last decade and more. Many of these strategies have been shown to successfully impact undergraduate physics students' conceptual understanding of fundamental physics principles in the studies in the last several years.

The EMIT model places the GTA into the role of content expert and cognitive coach who shares expertise in physics content and concepts with the novice physics student, interacts with cooperative student groups during problem-solving and applies progressively fading scaffolds (support and guidance) during model-building. In Figure 3, areas of research synthesized in the EMIT model are shown below.

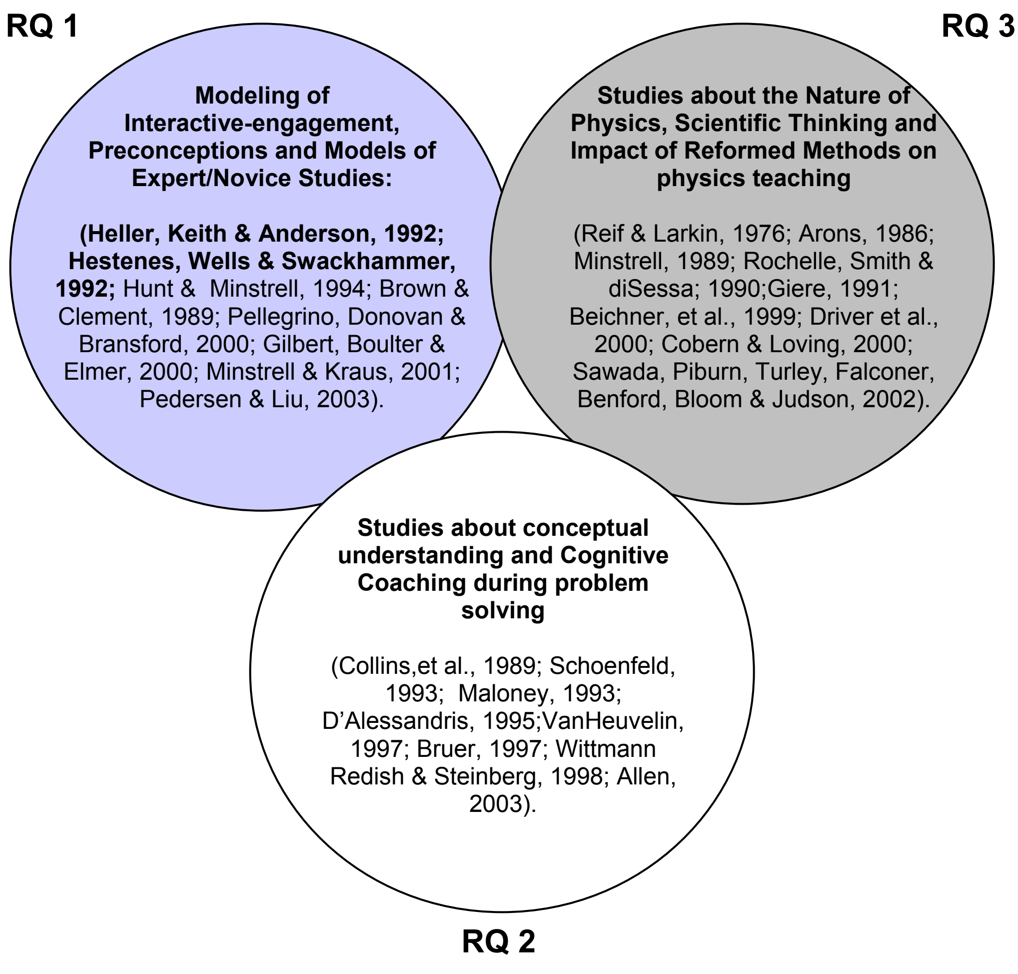


Figure 3 EMIT Synthesis: Supporting Research Studies

The EMIT model is organized around elements of the studies examined.

Learning Science Means Understanding Scientific Reasoning

Giere (1997) defines the process of learning scientific information as one in which the learner must first possess a basic conception about what science is (a conceptual model) and what the process of acquiring scientific knowledge requires. Developing this understanding of the nature of scientific reasoning is vital to any fundamental grasp of science and also must take place within the scope of the purposes of science (Driver et al., 2000). The interplay between Giere's four relationships: 1) the Real World, 2) A Model, 3) Real World Data and 4) Predictions based on data, characterize scientific understanding. See Figure 4 for articulation of the four elements in the Giere model.

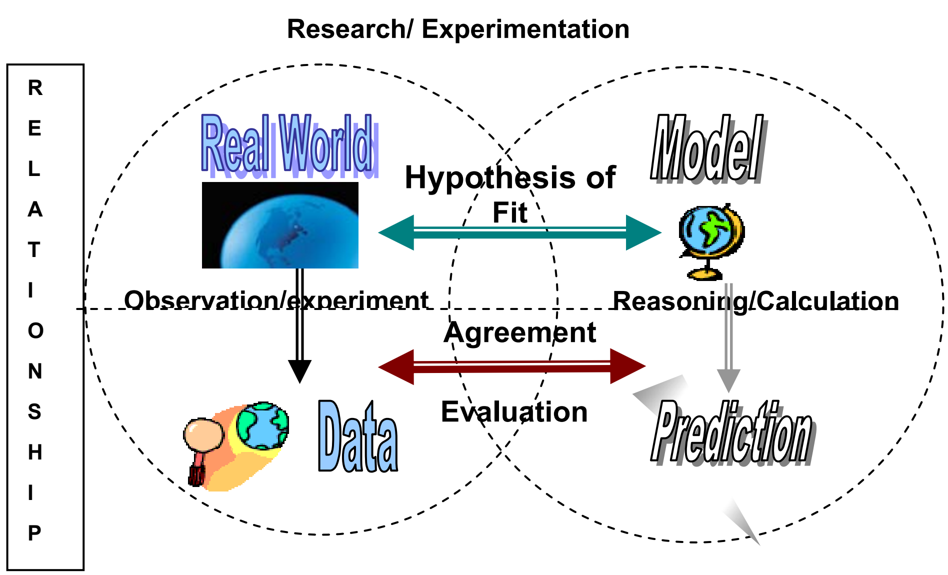


Figure 4 Four-Element Model for Understanding Scientific Reasoning (Giere 1997)

Further, Pellegrino, Donovan and Bransford (2000), Minstrell (2001) and others have found that preconceptions that students bring to the study of science, if not directly made visible, can impede learning and understanding of new concepts. These naïve conceptions are stubbornly resistant to change and may exist side-by-side with competing models and explanations of the same scientific phenomenon.

The process of moving from novice to expert depends on the student recognizing the thought processes scientists use and the views that scientists hold about the nature of science. Recognizing and validating students' in place beliefs can help them differentiate their present ideas from, and integrate them into, more mature conceptual beliefs similar to those scientists hold (Minstrell, 1984). Ideas about science that constitute a scientific worldview are interpreted and articulated through a person's actions (Loving, 1998).

Bridging strategies (a type of scaffolding) have been used in science instruction. Brown and Clement (1989) addressed the process of addressing students' misconceptions, but in addition, then "bridging" to the correct beliefs that students already held (Gilbert & Watt, 1983). This process is called "anchoring conceptions" and allows the student to confront the inconsistencies inherent in holding two conflicting ideas, simultaneously. Hunt and Minstrell (1994) also see instruction as "fostering reconstruction of understanding and reasoning," rather than the memorization of facts and answers. Interceding as students are constructing knowledge as a "teachable moment" or "Just-in-Time" opportunity, allows the instruction to impact the student more significantly (Novak, Patterson, Gavrin & Christian, 1999).

Learning is very much influenced by the context in which it occurs. Finkel and Monk (1983) explain that the traditional approach to teaching is at odds with an instructor's own experience of effective learning. Real world connections and student-centered inquiry methods have been demonstrated to establish a classroom atmosphere more conducive to the learning of science. Alan Schoenfeld (1993) developed a group problem-solving method, used in a college mathematics class, that focused on students' taking charge of their own conceptual development and problem solving so that students became more metacognitively aware (Redish, 2003). Students were constantly referred to the process by the posted reminder seen in Figure 5.

1) What (exactly) are you doing?

(Can you describe it precisely)?

2) Why are you doing it?

(How does it fit into the solution)?

3) How does it help you?

(What will you do with the outcome, when you get it)?

Figure 5 Schoenfeld's Focusing Questions

Arons (1986) analyzed student thought during problem solving in introductory physics classes, carefully constructing questions in order to "elicit" that thinking. Arons and others have arrived, through conducting careful studies, generalizing and replicating their experiments, at effective strategies for physics instruction that emphasize the listening and observing of student learning, making thinking visible (Arons, 1986: Minstrell; 1989: Minstrell & Kraus, 2001).

Minstrell (1989) and diSessa (1988) both have developed frameworks to help make sense of students' reasoning and to address student thinking in a "fine-grained" manner. Minstrell, during careful research in his own classroom, developed the idea of identifiable pieces of student knowledge (facets) while diSessa defined students' primitive conceptions (p-prims) as conceptual tools for instruction.

When questioning students, a balance is needed between intervening too soon (curtailing student' explorations) and waiting too long (frustrating the process). If students' initial forays into forming answers and constructing models for problem solutions are met with encouragement and support, and summarizing occurs at the end of the process, students feel they have reached closure for the task. It is important to encourage students to take risks and seek validation that they are "on the right track" or at least have made some positive steps as instructors guide them from novice to a more expert understanding of the concepts.

There is widespread agreement by many educational researchers that prior experience and preconception of physical situations can be at odds with newly presented concepts (Brown & Clement, 1989; Rochelle, 1995).

Consequently, learners will distort this presented material, learning something opposed to the educator's intentions, no matter the quality of the lesson (Roschelle, 2000). Minstrell and Kraus (2001) have developed classroom techniques for gradually restructuring students' conceptions by identifying students' facets of learning. Roschelle (1991) studied students' learning from similar computer software and concluded that students learn the scientific concept of acceleration through a series of gradual transformations of their prior knowledge.

Research on the Elements of "Reformed" Physics Instruction

Over a four-year time span, several departments at North Carolina State University offered experimental sections of courses taken by freshman engineering students in a highly collaborative, technology-rich, activity-based learning environment which incorporated the acknowledgement of students' prior knowledge, the Scale-up Project (Beichner, Bernold, Burniston, Dail, Felder, Gastineau & Gjertsen and J. Risley, 1999). In the three phases of the project, studies that made comparisons to traditional instruction have shown significant improvement in student performance in 1) problem solving, 2) conceptual understanding, 3) improved attitude toward physics and 4) much higher success rates for females and minorities (Beichner et al., 1999).

The Visual Physics design drew philosophically and thematically from The Minnesota Collaborative Model (Heller et al., 1992), which is based on a reformed coordinated structure of lectures, labs, and recitation sections. As is traditional, lectures given by the professor are complemented with labs and recitation, which are conducted by graduate student teaching assistants (GTAs). The major focus of the Minnesota Model is the learning of physics through cooperative group problem solving through an instructional design that is organized to target students' learning needs (Heller, et al., 1992). The Minnesota Collaborative Model incorporates problems that are context-rich in nature and constructed with a "story line," in order to provide students with a conceptual framework in the learning environment (Heller & Hollabaugh, 1992).

Multiple representations by students and interactions between the instructor and student are encouraged by the techniques in Overview Case Studies and in Activphysics (Van Heuvelen, 1991a). This process encourages students to begin to think like scientists. And, in this way, students learn to represent complex problems by representing their parts, using words, sketches, diagrams, graphs and equations.

Given a complex task in an Experiment Problem format, as seen and described in Figure 5, students then represent multiple aspects of it and construct a suite of representations. If given an equation that applies a basic physics principle in order to describe some process, a student should then construct other representations of that process including a word description and a picture-like description (Van Heuvelen, 1997). For a more complete interactive experience, students can view video and simulations and mathematical examples online. The Model Analysis part of The Physics Suite materials, (Redish, 2003), a compendium of physics reform studies and strategies, incorporates much of the best in learning theory to change the traditional practice of physics teaching and learning. Based on years of extensive research, bridging the fields of physics and education, this program integrates textual and web-based materials aimed at a new generation of physics students (Redish, 2003).

Research underpinning The Physics Suite is based on three basic considerations: 1) real observations of student behavior in classrooms; 2) controlled experimental studies aimed at cognitive processes of students, during instruction; and 3) a "physiological plausibility – a neurological basis for learning (Stanley, 1999).

Introductory physics students' use of multiple models during problem solving was examined (Wittmann, Steinberg & Redish, 1998). Studies show the outcomes we expect physics students to achieve (expert problem-solving skills) and what we actually test (algorithmic exercises with pattern matching) cause a mismatch between what is taught and what is learned (Redish, 1998). Student understanding of fundamental physics principles have revealed that conceptual understanding and mathematical acuity do not always go hand in hand (Sabella, et al., 1997). Within the confines of each model, a careful study of the kinematics, dynamics, and conservation laws are undertaken. The text that accompanies The Physics Suite is *Understanding Physics,* an adaptation of the traditional calculus-based course to a more interactive engagement methodology (Cummings, et al., 2003).

Other Studies on Effective Physics Teaching

Reif & Heller (1982) did one of the earliest studies on problem solving among physics students. This study attempted to get students to be more systematic in their problem-solving strategies revealing a prevalent tendency of students to “grab an equation and plug in numbers” (Maloney, 1993). Learning in interactive physics environments allows students not only to make decisions about the physical situation that is represented, but also to interact with it, proceeding from familiar schemas toward constructing new ones. Learners can succeed in conceptual change as long as appropriate care is taken in acknowledging students’ ideas, embedding them in an appropriate social discourse, and providing ample support for the cognitive struggles that will occur (Roschelle, 1995).

In a study of student misconceptions in science and mathematics, the role of prior understandings in the learning process was defined as a productive and necessary starting point in a process of “cognitive growth” for the learner (Smith diSessa & Roschelle, 1993). See Table 3 for additional examples of studies working on reformed methods.

Table 3 *Introductory Physics Reform Studies*

Research from Physics Reform	Description of the Research
Overview Case Studies/Activphysics (Van Heuvelen, 1991).	Given a complex task in an Experiment Problem format, students then represent multiple aspects of it and construct a suite of representations. Multiple representations by students and interactions between the instructor and student are encouraged by these techniques.
The Minnesota Collaborative *Model* (Heller, Keith & Anderson, 1992).	The major focus of the Minnesota Model is the reform of all elements of the physics course – lecture, lab and recitation. Learning physics is done through cooperative group problem solving and through an instructional design that is organized to target students' learning needs. This model requires a change in beliefs about teaching by instructors of the course that often default to lecturing students, since this is the only model of teaching most have seen.
Peer Instruction (Fagan, Crouch & Mazur, 2002)	PI survey results indicate that most of the assessed PI courses produce learning gains commensurate with interactive engagement pedagogies, and more than 300 instructors (greater than 80%) consider their implementation of Peer Instruction to be successful. Over 90% of those using the method plan to continue or expand their use of PI. Over 700 instructors completed the survey, 384 of whom use Peer Instruction
Physics by Inquiry (McDermott, 2001);	Physics by Inquiry emphasizes discovering, rather than memorizing. Teaching is done through *questioning* rather than *telling*, allowing time for open-ended investigations, dialogues between the instructor and individual students, and small group discussions. A major goal is to help students think of physics as an active process of inquiry in which they can participate
Modeling Methodology (Hestenes, Wells & Swackhamer, 1992).	Science instruction should be designed to engage students in making and using models. Since scientific models are coherent units of structured knowledge used to organize factual information into coherent wholes, the structure of scientific knowledge is made more explicit for students by using a few basic models. Students learn transferable modeling skills by applying models to a variety of situations to describe, explain, or predict physical events.
Real Time Physics (Thornton, 1997).	Focus is primarily on the evaluation of student conceptual understanding of mechanics (kinematics and dynamics) with an emphasis on Newton's 1st and 2nd laws in introductory courses in the university. Student understanding of mechanics was looked at before and after traditional instruction. It is examined before and after Microcomputer-Based Laboratory (MBL) curricula that are consciously designed to promote an active and collaborative experience for students. The results show that the majority of students have difficulty learning essential physical concepts in the best of our traditional courses where students read textbooks, solve textbook problems, listen to well-prepared lectures, and do traditional laboratory activities. Students can, however, learn these fundamental concepts using MBL curricula and Interactive Lecture Demonstrations that have been based on extensive classroom research.
Model Analysis (Bao & Redish, 1999),	Model Analysis is used to look at the results of instruments where students are assumed to be in a “mixed state” – a state which, when probed with a set of scenarios under diverse contextual settings, gives the probability that the student will choose a particular mental model to analyze the scenario. These results are tied to scores on the Force Concept Inventory, a research-based multiple-choice instrument developed to probe student’s conceptual understanding of Newtonian Mechanics in a physics class.
Just-in-Time Physics (Novak, et al. 2001)	Just-in-Time Teaching (JiTT) is a teaching and learning strategy-using interaction between web-based assignments and an active classroom. Students respond to carefully constructed web-based assignments due before class. The instructor reads the student submissions "just-in-time" in order to adjust the lesson. Thus, the heart of JiTT is the "feedback loop" formed by the students' preparation and the subsequent in-class time together.
Socratic Dialogs (Hake, 1992)	Socratic Dialogs emphasize “heads on” thinking during experiments and facilitate interactive engagement of students with the laws of mechanics. They were originally inspired by the work of Arons (1986,1990) and embody many of his instructional methods. Arons' methods were, for the most part, empirically derived but are consistent with much of the recent research (Bransford, et al. (1999), Redish (1994) and Heller et al. (1995).

Learning in interactive physics environments allows students not only to make decisions about the physical situation that is represented, but also to interact with it, proceeding from familiar schemas toward constructing new ones. Learners can succeed in conceptual change as long as appropriate care is taken in acknowledging students' ideas, embedding them in an appropriate social discourse, and providing ample support for the cognitive struggles that will occur (Roschelle, 1995). In a study of student misconceptions in science and mathematics, the role of prior understandings in the learning process was defined as a productive and necessary starting point in a process of "cognitive growth" for the learner (Smith, diSessa & Roschelle, 1993).

Further, Roschelle (1991), in an analysis of "conversational interactions," examined an integrated approach to collaboration and conceptual change in group problem-solving situations. He defined collaboration as a process that gradually leads to a "convergence of meaning" for the participants.

The American Association for the Advancement of Science in *Science for All Americans* (1990) emphasizes and recognizes that examining how science is taught is equally important as investigating how it is learned. In planning instruction, effective teachers draw on a growing body of research knowledge about the nature of learning and knowledge about teaching that has stood the test of time. According to Arons, (1986) a "stream-of-words" lecture approach is not the educational answer. The onus should be on the instructor to listen to the student talk during problem solving.

Extending and investigating the “facets” of understanding students have about mathematics and physics concepts, Minstrell (1994) designed a way to get at student thinking about physics, code it and suggest remediation, through the program *Diagnoser*. Using the “facets” of student understanding provides a means of revealing student thinking during conceptual modeling of multiple related science or mathematics concepts. Using experimental evidence and rational argument, the researchers addressed questions of “how do (students) know” and “why do (students) believe,” (Minstrell & Stimpson 1996; Minstrell 2000).

If graduate teaching assistants are trained to intercede at moments of student difficulty -- “Just-in-Time” opportunities -- they may be most effective in promoting the maturation of student reasoning, from novice to more expert-like in character, as is illustrated in the table on page 48. A later section will focus on the character of expert/novice research by Reif, Larkin & Bracket (1976), Clement (1982), McCloskey, (1983), Sternberg & Horvath (1995), Minstrell (2001).

Research on the Impact of the Nature of Science on Learning

The phrase "nature of science" typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent in the development of scientific knowledge. The essence of science is the observation and exploration of the real world in order to identify underlying patterns (French, 1998). According to physicists, consensus on successful approaches to investigating science can be established by encouraging appropriate interactions among scientists (Giere, 1988).

Cobern and Loving (2000) conduct a case study of four high school science teachers and their ninth grade students. This study was part of a larger study that compared ninth grade science students and their teachers' conceptualizations of Nature and how they invoked scientific ideas. The findings revealed that teachers spoke more about science and in more depth about science than their students (Cobern, 2000). Further, Cobern and Loving (2000) claim that science teachers *ought* to explicitly show their enacted scientific worldviews to promote understanding in their students that science can be interpreted and made meaningful in various ways by novice and experts alike.

The Nature of Physics and Physics Teaching

Brian Greene, any definition of the nature of physics should also include "the search for pattern and regularity in natural phenomena and the development of simple laws that codify such patterns in a predictive manner (Greene, personal communication, May 1, 2004). In a study of high school physics students' learning strategies, students more often memorized isolated bits of information, applied formulas by rote or looked for an appropriate algorithm rather than reason through a physics problem. Students had trouble making connections between "common knowledge" and what they were learning in physics (Hammer, 1994).

Students' epistemologies may impact their reasoning, strategies, and participation. Paying attention to students' beliefs may help to illuminate areas of misinformation and facilitate a deeper understanding about where students' prior ideas inhibit instruction. Through careful examination, and making connections with the conception students already have in place, can be ascertained and an adaptation of strategies for instruction can be tailored to the students' needs (Hammer & Elby, 2002).

Student-to-Graduate Teaching Assistants' Relationships

Many beginning graduate teaching assistants do not receive effective (or any) instruction in teaching strategies and communication skills needed to teach effectively. Decades of good physics education research have found that, although GTAs may be expert problem solvers, they lack the skills to develop that knowledge in students during recitation and lab (Saul, 1997). Also found to be lacking is the ability of graduate teaching assistants to be able to communicate concepts and engender conceptual understanding among introductory students. According to Arons (1986) and others, an instructor needs patience – listening, observing and engaging in appropriate "wait-time" as students cooperatively solve problems. The graduate teaching assistant should act as a resource and guide, validating student efforts (Novak et al., 1999).

The Role of the GTA in the Articulation of the Introductory Physics Course

Traditional introductory physics instruction is often ineffective in helping students to develop a real understanding of the fundamental concepts in physics. Too often, physics instructors are disconnected with the lab and recitation (discussion) sections in which students also participate. Many physics instructors do not even interact or interact at a minimum with the graduate teaching assistant assigned to their sections. As a result, the parts of a traditional physics course are not aligned, students do not know the expectations of the professor, especially as it concerns the lab and recitation, and exams may not be designed to capture the important concepts professors want their students to learn.

Bao and Lee (2001) in a study of physics graduate teaching assistants views about the nature of physics and physics teaching, found a mismatch between graduate students' major views and undergraduate students' views. Since graduate students (as content experts) have a major impact on student (novice) learning in introductory physics graduate student beliefs directly effect how introductory students learn concepts and develop their own beliefs about the nature of physics.

Pedagogical instruction for graduate teaching assistants (and more and more professors, themselves are articulating that they would like to have had such a course for themselves) can prepare them for a more interactive role with students, enhancing and making the process of learning physics concepts more efficient, (Boyer, et al., 2001)

All parts of the introductory physics course can become more powerful and successful if students become *active participants* in their own learning

(Heller & Hollabaugh, 1992). If graduate teaching assistants are prepared for an instructional role that parallels and enhances student learning of basic principles gained in lecture and homework, they then can guide students toward more expert-like understanding of the fundamental concepts of physics (Pruitt-Logan, Gaff & Jentoft, 2002).

Further, if graduate teaching assistants also learn to design instruction that promotes coherent understanding across topics and during problem solution, they then can demonstrate their "expert" grasp of content while applying interdisciplinary contexts and real world applications (Jossem, 1999). As graduate teaching assistants engage in Socratic questioning strategies in order to re-focus student groups, they use a variety of representations to characterize physics concepts. Graduate teaching assistants' questions encourage students to engage in divergent modes of thinking and mental model building through an induction process (Heller, et al., 1992; Hake, 1998). In a study of physics students at the Air Force Academy, Novak, et al. (1999) found that student questions and comments shape interactions with graduate teaching assistants capitalizing on "Just-in-Time" opportunities to intervene and guide student thinking, encouraging participation and an expectation for student contributions.

Research on the Cognitive Apprenticeship Model

Teaching Is Cognitive Coaching

One of the obstacles to innovation in introductory college classes has been the problem of scale (Pellegrino, et al., 2000). Many studies have demonstrated techniques for tackling this problem successfully (Reif & Heller, 1982; Larkin, 1983; Van Heuvelen, 1990; Hestenes, et al., 1992; Heller, et al, 1995).

High-tech as well as low-tech solutions has been offered. The SCALE-UP program at North Carolina State University is one method that incorporates both. The processes undertaken by students are called "ponderables" and are integral to the Scale up Project which uses a framework of highly collaborative, hands-on, computer-rich, interactive learning for undergraduate physics courses (Beichner, 2004). Ponderables are problems that are often not well defined, so that students have to synthesize relevant information, use estimation and decide which solution model to use in order to determine the approach that works best for their team.

Cognitive Apprenticeship, as a learning strategy, involves the following elements: 1) helping students toward more mature reasoning skills, 2) designing interactive environments, 3) use of a "cognitive coach" (expert) who focuses on the students' learning tasks and 4) modeling thinking like a professional (Schoenfeld, 1985). In this model, the novice (student) begins to assume more of the role of task–solver with support (scaffolding) from the expert (GTA). There is little or no direct teaching (traditional lecturing) between expert and novice (Collins,et al., 1989). Emphasis should be on the novice as a member of a larger learning community whose design needs to provide the novice with access to the larger “community of learners” that supports the novice toward a more expert practice.

In the Minnesota Model (Heller, et al., 1992), from which this study drew inspiration, graduate teaching assistants monitor students actively participating in student cooperative groups, engaging in intellectual dialogue, debate, negotiation, interpretation of concepts, and formulation of solutions (Heller et al., 1992).

In this study’s reform of recitation, embedded within the larger Visual Physics reform study, the graduate teaching assistants were first explicitly and extensively trained in methods of interactive-engagement pedagogy and the cognitive coaching methods used in guiding student learning. GTAs evaluated and modified materials, used for problem solving in recitation and practiced with the instrument used to evaluate their teaching (RTOP). GTAs then modeled the methods they expected students to follow, empowering students to take some control of and be responsible for their own learning.

By guiding and coaching students while they are problem solving, graduate teaching assistants model expert performance as students break down complex physics scenarios into more manageable pieces. Students incorporate multiple representations in their solution models as well (Heller, et al. 1992; Van Heuvelen, 1991b).

Research on the Characteristics of Expert and Novice Problem Solving

Carey (1986) has pointed out that change happens, in a domain, as the novice moves toward more expert practice. Chi, Glaser and Rees (1982) have described this process in mathematical problem solving. An analysis of misconceptions, similarities among elements in the domain of learning, and a fine-grained look at the process of problem solution are all imperative (Carey, 1986). Looking at the type of misconceptions students hold may also help to categorize the degree of novice-like practice from the expert (Clement, 1991; McCloskey; 1983). Larkin (1983b) found that capturing the "novice-expert shift" should be descriptive. Change, for the student, necessarily involves an uncomfortable restructuring of knowledge as relations between concepts are reordered and new abstract concepts are created (Larkin, 1983b).

Bruer (1997) determined that there are "qualitative differences among types of learning opportunities." In this study, seventh graders who successfully performed a task (e.g. reading aloud) did improve their reading skills, but that improvement did not necessarily translate into comprehensive of what they read. A process of "reciprocal teaching" (applying the results of cognitive research to reading instruction) has been found to greatly enhance student comprehension and retention as well as the ability of the student to apply what was learned to novel situations (Palincsar & Brown, 1984). Four strategies were identified as needed in order for students to reach comprehension when reading: 1) summarizing, 2) questioning, 3) clarifying and 4) predicting. Further, strategies based on these results were shown to aid novices in applying these operations through dialogue. Modeling of these methods for students have impacted restructuring the learning environment in other content areas, as well (Bruer, 1993). In the development of a prototype of expert teaching, Sternberg and Horvath (1995) delineate a *set of characteristics* of expert teaching in order to distinguish teachers who are truly experts from those who are merely experienced. They point out the former lack of "well-defined standards" to apply to the two populations mentioned. In an attempt to look in a fine-grained fashion at a gradation of the process of classification of expertise, they use two major types of categories – "similarity-based" and "prototype-centered." They attempt to carve out a middle ground, classifying teachers, to identify the "degree to which" a teacher fits. The prototype-centered model has three properties: 1) teachers fit the prototype on different features; 2) there is differential weighting of the features, themselves; and 3) features in categories are correlated and occur together in a category (Sternberg & Horvath, 1995).

Expertise in a particular content area does not guarantee expertise in teaching others to learn it. In fact, expertise can sometimes be counterproductive to good teaching because many experts forget what is easy and what is difficult for students (Bransford, Brown & Cocking, 2000). Larkin, McDermott, Simon and Simon (1980), compared the problem-solving behaviors of experts (defined as graduate students and physics professors) with novice physics learners (first-year physics students). Through the application of their computer models ("knowledge-development" and "means-end") they found that the problem solving of experts more often adhered to the former (forward working), while the problem solving of novices more often resembled the latter model (backward working). In a separate study, Sweller, Mawer & Ward (1983) proposed that the novices' use of means-end strategies were precipitated by the type of problems traditionally found in physics textbooks. And, when faced with more interesting problem structures that encouraged a conceptual understanding, novice problem solving took on a more mature complexion.

Often students naively view physics problem solving as an attempt to determine the value of unknown physical quantities. But this approach is not the technique used by most successful physicists (experts). The outcome of a study on conceptual understanding revealed that the informal knowledge of students about physical phenomena strongly affects what they learn (Van Heuvelen, 1991a). Incorporating Larkin, et al.'s (1980) idea of "sequence of representations," Van Heuvelen developed a strategy called "multiple representation problem solving." During this process, students use multiple methods incorporating 1) sketches, 2) organizational structures to design their problem solution, 3) labeled free-body diagram(s), 4) relevant equations along with their derivations and 5) solutions and comments. This model encouraged shifting the focus from the solution to the process and model of problem solution. See Table 4 for key principal characteristics of novice versus expert practice.

Minstrell (1984; 1989) developed a method of “cognitive orientation to teaching,” conducting many years of research into the way high school students learn physics and into how the role of prior conceptions impacts learning. Developing benchmark lessons (“What are your ideas, right now?”) as a result of his findings, Minstrell (1984) identified the “targets for change” needed to help students learn physics. His students gained a better understanding of physics because they learned more expertise in representation and had more mature understanding of concepts (Bruer, 1997). According to Minstrell (1989), time is the key to adequate processing of information for students.

> We must provide the time students need for mental restructuring. Hurrying on to the next lesson or the next topic does not allow for sufficient reflection on the implications of the present lesson (p. 147).

In another approach, D’Alessandris (1995) in the development of Spiral Physics has constructed problems that focus on the process and greatly minimize any numerical solution. Students build a solution model that incorporates 1) analysis of the physical situation, 2) explanations for what is happening, 3) selecting necessary values and 4) determining which values are most important to find. In another approach, D’Alessandris (1995) in the development of Spiral Physics has constructed problems that focus on the process and greatly minimize any numerical solution.

Table 4 *Key Principal Characteristics of Novice vs. Expert Practice*

Domain*	Novice	Expert
Knowledge Organization (Efficiency)	**Incomplete Few connections between ideas**	**More complete Connection between ideas, structured**
Classification	**Based on trivial features**	**Connects with fundamental concepts**
Planning (Analysis)	**Little or disorganized**	**Organized method of solution**
Approach (Insight)	**Work from formulas**	**Works from concepts**
Evaluation (Solution)	**Little**	**Evaluates as progresses, checks for reasonableness**

These are based on the definitions given by Sweller, et al. (1980), Larkin, et al, (1983). The classification is not a distinct one but more of a gradation of features according to Sternberg & Horvath (1995).

Students built a solution model that incorporated 1) analysis of the physical situation, 2) explanations for what happened, 3) selected necessary values and 4) determined which values are most important to find.

The above research studies, as well as many others, have shown that having students solve traditional, de-contextualized and rote problems is not useful in helping them gain a larger picture in physics, one which also incorporates the concepts, fundamental principles and relationships that expert problem solvers have (Maloney, 1997).

The Importance of Models to EMIT

The structure of scientific knowledge can be made more explicit for students by organizing course content around a small number of basic models (Halloun & Hestenes, 1985). A model in science is a representation of a phenomenon with a specific purpose in mind, and modeling itself is a process by which models are produced as tangible outcomes of that process (Gilbert, Boulter & Elmer, 2000).

According to Driver (2000), science is defined as knowledge about the real world as well as a set of processes through which new discoveries are made. Models can be used to simplify, clarify and focus evidence gathered and observations made during the practice of science. The process of scientific discovery occurs for the learner through a variety of methods, strategies and techniques, dependent upon the questions asked and the design of the learning environment. Although theoretical models can be conceived of as part of an imagined world, through the application of appropriate and explicit instructional strategies, the learner's *naïve operational conceptions* about the nature of science and scientific processes can mature (Giere, 1999).

The Process of Model Building

According to a study by Gunstone and White (1998), discovery must involve a "deep processing" and a construction of meaning through the application of cognitive strategies that are not innate but "constructed over time." In order to achieve conceptual change, the student must feel dissatisfied with the existing concept, and that the new concept must be intelligible, plausible and fruitful. The ability of students to make and use models also depends on the representational tools at their command. Students learn modeling skills by applying models to a variety of situations in order to describe, explain, or predict physical events or to design experiments (Hestenes, 1996). According to a study undertaken by Hammer and others (2002) at the University of Maryland classroom observations show variability in student reasoning, from young children through adults, even moment-to-moment for the same students in the same class. Hammer (2002) cautions, however, about leaping to assumptions about the resources students bring to bear on solving problems in physics. The emphasis should initially be on discovering student thinking and throwing away old assumptions, which may be misguided.

Alien Rescue is a hypermedia instructional program designed to engage 6th graders in solving a complex problem. Multiple pathways are possible and students are empowered to make decisions. Pederson and Liu (2003) constructed the game where students assume the role of scientists to engage in cooperative problem solving. This problem-based activity includes the following:

1) Situating a problem in a rich context, allowing students to engage in scientific inquiries modeled after the processes experts employ

2) Presenting the full complexity of the problem while providing support tools for students

3) Providing multi-media-based information in order address different learning styles an other varied student needs

4) Providing experts' guidance to facilitate knowledge acquisition and transfer, using multiple perspectives

5) Emphasizing the interrelated nature of knowledge while providing connections to other curriculum areas

Although models are by their very nature an abstraction from a complex world and are incomplete, students begin to gain understanding of basic principles in physics by their use (Driver, 2000).

> Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge for teachers lies in helping learners to construct these models for themselves, to appreciate their domains of applicability and, within such domains, to use them. If teaching is to lead pupils toward conventional science ideas, then the teacher's intervention is essential, both through providing appropriate experiential evidence and making the theoretical ideas and conventions of the science community available to pupils (Driver, 2000, p. 6).

Graduate teaching assistants, as instructors in recitation and lab, can intercede effectively if given interactive teaching tools. Cognitive research has shown that learning is most effective when four fundamental characteristics are present: 1) active engagement of students in the lesson, 2) participation in a group setting, 3) frequent interaction with feedback and 4) connections to real-world contexts are present (Roschelle et al., 2000). Further, Collins et al. (1992) propose that richer and more lasting knowledge acquisition ensues as a more in-depth probing of students occurs.

RTOP: Assessment of a Reformed Teaching Model

The Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) designed the a widely known Reformed Teaching Observation Protocol (RTOP) that assesses teaching based on constructivist models and is patterned after the Cognitive Coaching Model (Sawada, Piburn, Turley, Falconer, Benford, Bloom & Judson, 2000). The RTOP evaluates teaching in these domains: 1) lesson design and implementation, 2) propositional content knowledge, 3) procedural content knowledge, 4) classroom culture – the quality and type of communication and interactions and 5) student/teacher relationships (Piburn, Sawada, Falconer, Turley, Benford & Bloom, 2000).

Further, MacIsaac and Falconer (2002) have broadened the definition and suggest an evaluation of “reformed” physics teaching that promotes articulation of all parts of the lesson, student-centeredness and conceptual understanding of physics, along with model-building skills in problem solving. Modeling is defined variously in the literature and a careful definition of those modeling strategies and definitions used is given in Chapter I of this study.

Research on the Role of Technology in Model Building and Problem Solving

As more and more instruction is given virtually via interactive technologies, the relationship-building capability of hands-on activities, simulations, and interesting questions as well as problems becomes crucial. Cognitive scientists Newell and Simon (1972) developed the first working artificial intelligence computer program, in an attempt to investigate in a systematic way how the mind works, thinks, remembers and learns through problem solving (Bruer, 1997). Technology as an integral part of course design is exemplified in the Just-in-Time Teaching Instructional method employed at Indiana Purdue University at Indianapolis (IUPUI) and the United States Air Force Academy, among others (Novak, et al., 1999).

Additional examples of the use of technology for assessment of student thinking are Diagnoser (Hunt & Minstrell, 1994) and Classtalk developed by Abramson and implemented at Vanderbilt by Bransford, et al., 1999). Technology-based, knowledge-centered formative assessments, using simulations, visualizations and video-based problem solving can help to reveal student thinking and naïve conceptions during problem solving and questioning tasks (Pellegrino, et al., 2000).

The use of technology for formative assessment is advocated by Black and Wiliam (1998). They argue that the core of assessment is derived by the perception by the learner of a *knowledge gap* and the action needed to be taken by the learner in order to close that gap.

Pedersen and Liu (2003) examined the transfer of problem-solving skills in a problem-based learning environment in order to examine students' transfer of strategies that were modeled by an expert for them. Using the computer game, Alien Rescue, students heard an expert model the process that they would be expected to perform, by "thinking aloud." The experts then followed this exercise with a *didactic condition*, through which they gave tips and examples of how to work effectively, followed then by the *helping condition*, where they explained the computer tool but did not provide support for problem solving. As a result, the researchers found that the modeling condition worked best and provided the most effective support of student's learning. They assert that the modeling of an expert's cognitive process, during performance of a task leads to optimum transfer of learning (Pedersen & Liu, 2003). The process of learning physics can engage students through the use of appropriate modeling activities -- a hands-on lab or online simulation -- and using the right instructional model can optimize development of physics concepts and process skills (Boulter & Gilbert, 2000). Through carefully crafting questions and employing interactive techniques, teachers can 'get at' students' naïve conceptions and help students confront, discuss, modify and reassemble them into a fuller picture and a coherent whole (Gobert & Buckley, 2000).

Summary

According to the Boyer reports (1998, 2001), undergraduate education in universities requires renewed emphasis on a point made by John Dewey that learning should be based on students' discoveries, guided by mentoring, rather than on the passive method of transmission of information as is so common in many introductory courses. The first year of a university experience should provide stimulation for intellectual growth, grounding in inquiry-based learning and communication of information and ideas. Techniques incorporated into the

EMIT Model developed in this study have spanned the definition from the models used by Hestenes et al. (1992) in defining the type of instruction teachers need to be effective, to the solution models designed by students as they engage in cooperative group problem solving.

If the learning and doing of physics is to be made responsive to most students, it is imperative to concentrate on how and what students understand (Redish 2003). This is a process that can carry over to all learning, not just to physics learning. Dealing with students' prior knowledge In order to move the student toward conceptual change, an anchor in prior experience must be established and discussed. Instructional designs must include modeling strategies that illuminate, analyze and make steps toward resolving conceptual conflicts. Consideration of the assumptions that are made about fundamental physics understanding through student experiences can positively impact the instructional design.

A careful design of the learning environment integrating the expert modeling of the process and products to be expected of students is warranted. Curricula created and refined using the best in physics education research can be significantly more effective than traditional methods. Relating the qualitative, conceptual understanding with the problem task provides a framework for thinking about how students organize knowledge and the differences between expert-novice problem solving (Gerace, 2001).

During the process of learning, the use of integrated, coordinated and interactive physics tasks can “pay back” in enhanced conceptual understanding for most students and optimize efficiency of content learning (Van Heuvelen, 1997). Deep understanding and expert-like problem solving skills stem from being able to conceptually understand tasks. The process of reaching a solution also assumes that the student has had the process modeled effectively by an instructor (or GTA) and is guided through that process by a careful attention to their thinking and to their needs. Leonard, Gerace & Dufresne (2002) suggest exploring the naïve conceptions of students and their beliefs about learning physics, prior to any problem-solving task. Bao & Lee (2001) suggest revealing the learning schemes of the graduate teaching assistant, who generally spends fifty percent of instructional time with introductory students. They also suggest that more research is needed into the way GTAs conceive of learning and teaching physics and their views about teaching and learning in general.

What has not been firmly established in the literature is if an explicitly-modeled, interactive-engagement method for graduate teaching assistant instruction, using Cognitive Coaching methods, brought to bear on student solution model-building during problem-solving will impact students’ conceptual understanding about fundamental physics knowledge. Further, it has not been shown whether changes in GTA thinking about the nature of physics and physics teaching translates into GTAs’ adherence to this new method and enhances student success in introductory physics. These questions are central to this study.

CHAPTER III

RESEARCH METHODS

> If you are a wise man you will observe your pupil carefully before saying a word to him.
>
> ─ Jean Jacques Rousseau, *Emile*

Research Questions

1 To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?

2 What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?

3 What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Introduction

Why Was a Mixed Methods Design Chosen for This Study?

Data acquisition in this study was undertaken through both qualitative and quantitative methods. The conventional wisdom among researchers is that these methods have different strengths, weaknesses, and requirements that affect evaluators' decisions about which methodologies are best suited for their purposes (Creswell, 2003). Data collected through quantitative methods are often believed to yield more objective and accurate information because the data collection: 1) use standardized methods; 2) can be replicated, and 3) unlike qualitative data, can be analyzed using statistical methods (Shavelson & Towne, 2003). It follows, then, that qualitative methods may be considered to be more suitable for formative evaluations while quantitative methods are: 1) more appropriate in judging the "value" of data and 2) applied to summative evaluations. Various configurations of both approaches are needed to satisfy the requirements necessary to any particular study, depending on the type of data sources and type of supporting evidence needed to answer the research questions.

In this study, quantitative methods were used to answer the research questions posed about whether student conceptual understanding and performance in the physics course was correlated with GTA instructional methods. These methods were applied in order to make correlations with the underlying assumptions, and also to be able to integrate descriptive perspectives, underscoring the importance of the practical significance of the results (Thompson, 2002).

All instruments were validated, based on accepted standards of reliability and construct validity and were well tested, prior to use, so that the most appropriate methodology and measure for data acquisition was applied. See Appendix A for an example the Reformed Teaching Observation Protocol (RTOP) instrument used in this study. Quantitative methods involved careful data collection where attempts were made to help participants understand the meaning of the questions asked and the instruments used. These methods included descriptive and multivariate statistical methods, employing Discriminant Function Analysis (DFA) in order to get at the amount of variance accounted for by the interactive effects of multiple measures, and where the group membership (dependent variables) were dichotomous (Grimm & Yarnold, 2003). The qualitative methods included pattern matching and coding of data from semi-structured interviews, video transcripts, simulation transcripts and student problem-solving scenarios (CPQs). Both quantitative and qualitative data were gathered from the GTA and student participants for both treatment (Visual Physics, VP) -- and control groups (Traditional, TR).

Using a quasi-experimental quantification design with clustered sampling of intact student groups provided a compromise between generalizability and the need to target specific details in order to get at important aspects of the small population of graduate teaching assistants with their larger sample of students (Shavelson, et al., 2003). Triangulation of data (using multiple correlated tools) was needed to reveal a comprehensive picture of the degree to which the interactive methods, modeled for and learned by graduate teaching assistants, actually transferred to students. Important also was the ability to tap the graduate teaching assistants' own perspectives about the nature of physics and how student learning was impacted by these interactive methods.

The data sources were varied and complex in this study, driving a need to use multiple measures to represent the GTA instruction as well as student outcomes. The EMIT model was synthesized from many sources and was used as a framework in the GTA instruction. The researcher also used elements of a Cognitive Apprenticeship model during GTA instruction that was subsequently applied by treatment (VP) graduate teaching assistants, providing a strong theoretical base for this study's design (Collins, et al, 1989).

The Pilot Study

A pilot study was conducted during the Spring Semester 2003 in a first attempt to assess the impact of graduate teaching assistants on undergraduate physics students. It employed cooperative group problem-solving techniques, two physics graduate teaching assistants, with their twenty-seven undergraduate physics students, were included in the study.

Table *5 Pilot Study Preliminary Findings for Physics 218 H*

Recitation Profile	**Intervention/Lack of Intervention**	**Findings**
• 21 Students • 2 GTAs (One Asian, one American) • Spring Semester, 2003	• Audio Observations and Field Notes • Web-based simulations • Cooperative Group Problem solving • No GTA training prior to or during the semester. • Students were not surveyed	• GTAs asked many questions about the rationale behind the cooperative group method and often did not apply what they were told unless the researcher was present • Students engaged in "parallel processing" independent of one another instead of cooperating in groups • Students were frustrated with the web-based materials and GTAs had trouble communicating with students about their concerns
Recommendations: • Full study should design GTA instruction and make it explicit. • A Cognitive Apprenticeship Model should be used for both the GTA instruction and subsequent application of this model to recitation instruction. • A model for expected behavior should be formulated. • Videoing of the recitation as well as standardized tests should be performed in order to provide baseline, formative and summative evaluations of GTA success and student learning.		

The graduate teaching assistants did not receive training on instructional methods and materials preparation prior to the semester. Interactive-engagement methods and cognitive coaching scenarios were explained, but not explicitly modeled for, the graduate teaching assistants, as they attempted to apply these methods to their teaching. It was from these preliminary findings, shown in Table 5 that the need to explicitly train graduate teaching assistants in the methods of interactive-engagement and cognitive coaching techniques were made clear.

The subsequent full study began with pedagogical instruction of the treatment graduate teaching assistants conducted during the last week in August, prior to the Fall Semester 2003. It was designed to model and practice the incorporation of interactive teaching strategies and cooperative group problem-solving scenarios into the instructional design of the one-hour weekly recitation sections of Physics 218. The process and subsequent application of this explicit instruction and modeling of the instructional methods used by graduate teaching assistants in the treatment group, as they applied interactive-engagement methods to their teaching, were videotaped, assessed and recorded.

The Participant Selection Process

Selection of GTAs

For this study, the procedure for selecting participant GTAs produced four graduate teaching assistants and their intact Physics 218 sections from a population available to three Texas A&M physics professors, who were teaching in the Fall Semester 2003.

The graduate teaching assistant population was comprised of all possible graduate teaching assistants (approximately 40) who made up the pool of GTAs from which the study GTAs were drawn and assigned to professors A, B or C. The project director selected the treatment GTAs as those who would be able to attend instruction prior to the Fall Semester 2003. The control GTAs were assigned the following week. None of the GTAs knew about the program prior to instruction. See Figure 6 for a description of the GTAs who were selected for this study.

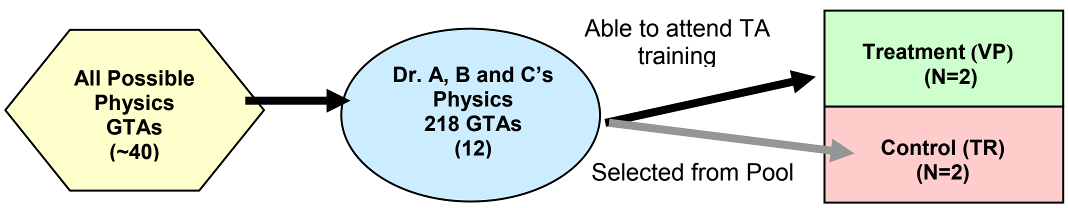


Figure 6 Description of the Graduate Teaching Assistant Sampling Frame

Selection of Student Recitation Sections

For profiles of the GTAs, see Table 6. There were two international GTAs, one in the treatment and one in the control group. The other two GTAs were from the U. S. The student sample, from which the supporting evidence of treatment (VP) impact was drawn, consisted of undergraduate students, mainly freshmen, between the ages of 18 and 23 who had taken (or were taking) calculus concurrently with physics.

Table 6 *TA and Section Profiles**

GTAs						Students		
	Age	**Ethnicity**	**Experience**	**Sex**	**Physics Prof.**	**#**	**Male**	**Female**
Treatment								
GTA “A”	23	U.S.	New to 218	F	A, B	14	10	4
GTA “B”	33	Korean	New to 218	M	B, C	12	8	4
Control								
GTA “C”	30	U.S.	New to 218	M	A, B	19	13	6
GTA “D”	26	Russian	New to 218	M	B	13	9	4

*Students with Missing Data on one of three measures have been omitted

All students had to have passed a series of math preparedness physics quizzes at the beginning of the semester in order to continue in the course. These students represented the larger population of Physics 218 students numbering about 1200. See Figure 7.

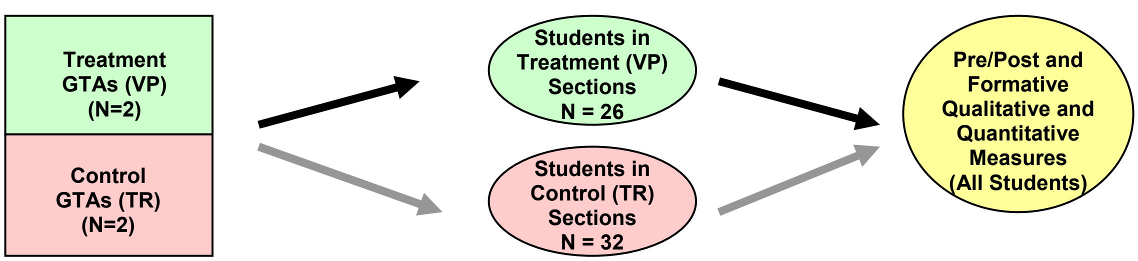


Figure 7 Description of the Undergraduate Student Sampling Frame

Students registered for sections were unaware of any differences in the pedagogical structure of the treatment (VP) and control sections.

Elements of the EMIT Model

In Figure 8 the core elements of the EMIT model are shown. EMIT is a unique, holistic and explicit approach to pedagogical instruction for GTAs in physics. The RTOP evaluation instrument was used during this explicit instruction. Modeling of questioning strategies, cooperative group interactions and the process of cognitive coaching formed the core of this model which was taught to the treatment GTAs in this study and applied to their recitation instruction. Control GTAs followed the traditional lecture-like model for physics recitation.

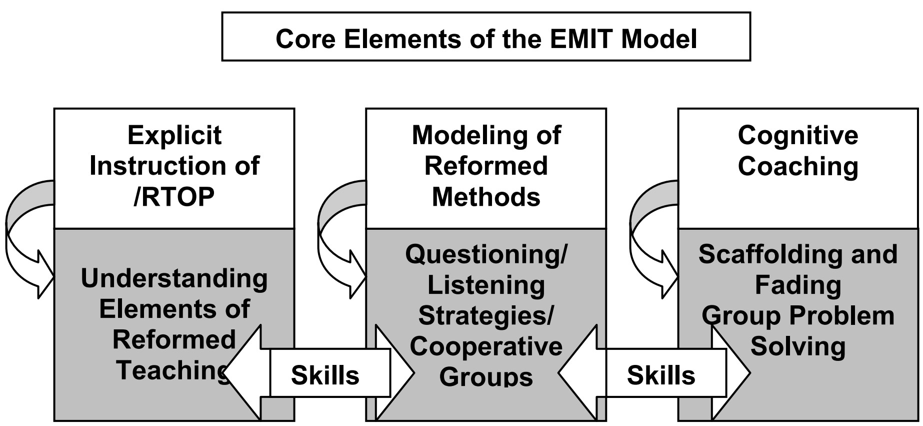


Figure 8 Articulation of the Elements of the EMIT Model

In Figure 9, minimum time requirements are shown for the application of the EMIT model is suggested in order to implement the model effectively.

Instruction, using EMIT is a cyclical and ongoing process with instruction revealing the need for revising, revisiting and renewing skills needed. A further discussion of suggested implementation can be seen in Chapter IV of this dissertation and reliability of each instrument organized by research question.

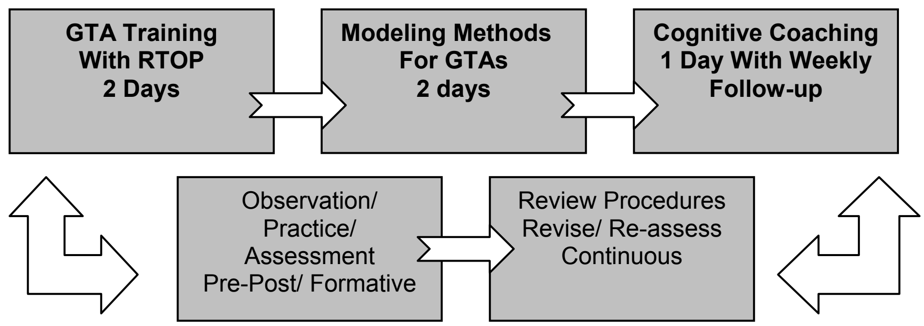


Figure 9 Suggested Implementation Model for EMIT

Finally, the section labeled “Methodology: Research Design” details the methods applied for each research question with a description of the application of each instrument.

Research Instruments Used

In Table 7, the instruments used in this study are listed, categorized and explained.

Table 7 *Classification of Research Instruments*

Instrument Type:	RQ	Given To Whom	Purpose/Method	When used	Analysis Methods
1. Force Concept Inventory (FCI) – Multiple choice	3	All Study Students	Measuring student conceptual understanding of basic principles of force and motion	Pre/Post Instruction	One criterion making up the Discriminant Functions effect size is also computed
2. Flash Mediated Force and Motion Concept Assessment (FM^2CA)	3	All Study Students	Measuring student conceptual understanding	2 Practice and 3 Formative	Sampled student comments and answers
3. MPEX2 Part I. multiple-choice Part II. Some free response	2	All GTAs	Measure of TA epistemological beliefs Part II includes nature of physics questions	Pre/post instruction	Scores compared between treatment and control groups Correlation with Student Surveys
4. RTOP for GTA Observation	1	All GTAs	As assessment of frequency and degree of adherence to methods modeled	Pre/Post and Formatively	Scores correlated to Student Survey results
5. Cooperative Group Problems (CPQs)	1,3	Treatment Students	To track students' problem-solving and model-building methods	Formatively	Qualitative coding and comparison between treatment and control groups
6. Traditional Recitation Problems	3	Control Students	Weekly problems and quizzes in control groups	Formatively	Used in control recitations only
7. Information Profile	2, 3	GTAs /Students	To gather background/baseline information	Pre Instruction	Qualitative coding and comparison
8. Semi-structured Interviews	1,2	All Study GTAs	To gather background and baseline GTA data	Pre and post GTA instruction	Coding and comparison With RTOP results
9. Student Survey	1,3	All Study Students	To measure GTA adherence to teaching methods (based on RTOP)	Formatively	One criterion making up the Discriminant functions Correlated with RTOP.
10. Final Course Grades	3	All Study Students	An overall assessment against the population of all Physics 218 students	Post -- End of Semester	One criterion making up the Discriminant functions
11. Video Observation	1, 3	GTAs/Students	To track GTA adherence to model and students' problem-solving	Formatively	De-coded using the RTOP Factor 3 items 9. 17. 19.

Validity and Reliability of Instruments

Quantitative Measures

For Research Question 1: GTAs' Adherence to EMIT Model

Reformed Teaching Observation Protocol

The RTOP was designed to capture the current reform movement, and especially those characteristics that define "reformed teaching." To do that, the authors of the RTOP relied heavily upon research in mathematics and science education and on the new national standards. This is characterized by an assumption that "knowledge is not transmitted directly from one knower to another, but is actively built up by the learner" (Driver, et al., 2000, pg. 5). It has also been shown to be imperative for reformed teaching that students engage in activities that call for them to reflect on their own work.

The Reform Teaching Observation Protocol (RTOP) has proven to be effective in evaluating mathematics and science instruction in middle and high schools, colleges and universities. With appropriate training, it is possible to achieve very high reliabilities using this instrument. Analysis of the RTOP suggests that it is largely an instrument that taps a single construct of inquiry. A finer-scale analysis lends new meaning to the phrases "pedagogical content knowledge" and "community of learners." The instrument seems able to measure what it purports to measure -- reformed teaching (Piburn & Sawada, 2001).

Reliabilities were estimated in a national physics and math verification of the RTOP instrument for the five subscales that constitute RTOP as shown in Table 8.

Table 8 *Reliability Estimates of RTOP Subscales*

Name of Subscale	R-squared
Subscale 1: Lesson design and implementation	0.915
Subscale 2: Content: Propositional Pedagogical Knowledge	0.670
Subscale 3: Content: Procedural Pedagogical Knowledge	0.946
Subscale 4: Classroom Culture: Communicative Interactions	0.907
Subscale 5: Classroom Culture: Student/Teacher Relationships	0.872

Estimates of reliability were obtained by doing a best-fit linear regression of one set of observations on the other. The face validity of RTOP draws on several sources among which are: 1) National Council Teachers of Mathematics, 2) Curriculum and Evaluation Standards, 3) National Academy of Sciences, 4) National Research Council, 5) National Science Education Standards and 6) Inquiry and the National Science Education Standards.

RTOP construct validity refers to the theoretical integrity of the instrument, the quantitative measure of the degree to which a class is taught in accord with science and mathematics reforms. The RTOP was designed to span a range of standards within the breadth of its five subscales, acknowledging the priority of “inquiry-orientation” (Piburn & Sawada, 2001). Evidence has been collected confirming the predictive validity of RTOP in four different university instructional settings: 1) in the evaluation of introductory biology, 2) mathematics, 3) physical science and 4) physics courses. The RTOP was also administered to instructors who had been trained (experimental instructors) and to instructors who had not (control instructors). Content pre and posttests were given in math, physical science, and physics and a scientific reasoning test was given in biology (Piburn & Sawada, 2001).

A factor analysis of the RTOP items was done and is shown in Figure 10. The group of three items exists at the intersection of Factors *1, 2* and *3.* The lesson is structured by the use of abstractions and other organizing devices. These items appear to define a cluster that could be called *REFORMED TEACHING* (Piburn & Sawada, 2001).

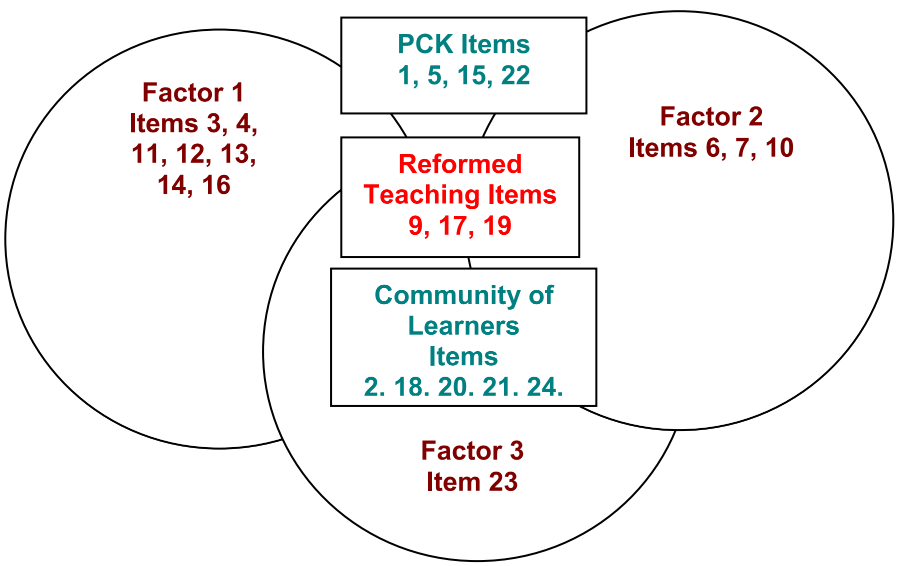


Figure 10 The Venn Diagram: Relationships among RTOP Items

Student Survey

One way to increase the accuracy of a survey is to use well-established measures, which have been demonstrated to be both reliable and valid (Trochim, 2004). To increase the accuracy of a survey, a well-established measure could be used which has been demonstrated to be both reliable and valid. This was done for the Student Survey. It was constructed to have a one-to-one correspondence with items on the RTOP. And, since validity and reliability have been well established for the RTOP, similar reliability and validity values can be assumed for the student survey.

Video Observation

The interactions of representative groups were analyzed both qualitatively and quantitatively using the clusters from the RTOP instrument and the same Likert scale. Video recording of the recitation sections was chosen for the reasons given by Smith (1981), namely that video taping usually gives greater flexibility than observations done by hand," allowing *retrospective analysis* and triangulation with other qualitative as well as quantitative data. Also, much greater depth in the analysis is possible compared to using techniques involving live coding (Bowman, 1994).

The videos were supplemented by handwritten field notes made during the observation sessions. These were designed to supplement data captured on the video recordings (such as interactions between groups not observed on camera). Digital photographs were also taken showing the positions of the computer, equipment, and the students in relation to each other and the GTAs as well as GTA adherence to the instructional model.

Tracking of the interactions controlled the coding which allowed the prevalence of features of reformed teaching to be recorded on a Likert scale for later analysis. The interactions between GTAs, GTA-student and student-to-student were transcribed from videotape onto coding forms. Quantitative analysis was used to determine how often GTAs engaged in various activities, and for how long. Much of the quantitative analysis was by means of event sampling, and the data from the coding forms revealed the frequency of some events such as the reformed teaching items 9, 17, 19 on the RTOP instrument. The videotape coding scheme organized the data, allowing for consistent analysis procedures.

Inter-rater reliability was achieved to within 93 % among and between graduate teaching assistants as they assessed themselves and each other's teaching modules and practiced scoring by negotiation as an instructional exercise on the instrument – the RTOP (MacIsaac & Falconer, 2002). Inter-rater reliability for the researcher was established by independent corroboration of video samples data by a second TAMU researcher (95.6%). Two additional national researchers also sampled portions of the video data, using the RTOP items, previously discussed and corroborated the results against means of researcher data, nationwide.

For Research Question 2: GTAs' Understanding of the Nature of Physics

MPEX2 Part I

The Maryland Physics Expectation (MPEX2) survey has been refined through testing in more than 17 universities and colleges during the last four years (Redish et al., 1998). Hammer (2002) building on prior work, subsequently proposed three dimensions along which to classify beliefs about the nature of learning physics: 1) *Independence,* beliefs about learning physics; 2) *Coherence,* beliefs about the structure of physics knowledge; and 3) *Concepts,* beliefs about the content of physics knowledge.

In the MPEX2 survey, Redish et al., (1998) probed the three additional dimensions of: 1) *Reality Link,* beliefs about the connection between physics and reality; 2) *Math Link,* beliefs about the role of mathematics in learning physics; and 3) *Effort,* beliefs about the kind of activities and type of work necessary to make sense out of physics. The view that agrees with that of most mature scientists as the “expert” or “favorable” view, and the view that agrees with that of most beginning students is the “novice” or “unfavorable view”.

For Research Question 3: Student Evidence of Conceptual Change

The Force Concept Inventory (FCI)

Physicists use a “technical” language for precise expression of scientific concepts as well as for careful description of physical situations. Unfortunately, until novice students understand the “expert” meanings, technical terms remain a barrier rather than an aid to understanding. Students often respond to form rather than meaning of technical language (Hestenes, 1996). For the typical physics course it was found that nearly 80% of the students could *state* Newton's Third Law at the beginning of the course, while FCI data showed that less than 15% fully understood it at the end (Hestenes & Halloun, 1995).

The design of FCI questions avoids "technical" language in order to get closer to what students really think. We reasoned that Newtonian thinkers would be able to resolve the consequent imprecision and ambiguities (Savinainen & Scott, 2001). Validation interviews confirmed this (Hestenes, 1996). The most important function of the FCI is that it sets a *minimal standard* for effectiveness of instruction in Newtonian mechanics. It is a discrimination test, requiring only that students make a forced choice between basic Newtonian concepts and naive alternatives. The Newtonian *concept of force* is complex, with six major components, which are revealed by student reasoning on the FCI (Hestenes & Halloun, 1995).

To the extent that students have not mastered complex concepts, they will repeatedly misinterpret what they hear and read in a physics course and they will be forced to resort to rote methods in learning and problem solving (Elby, 1999). Hake's (1998) data supports the contention that problem solving is a skill that depends upon concepts assessed by the FCI. Therefore, an emphasis on problem solving without attention to concepts will reinforce "mindless plug-and-chug by rewarding it" (Redish et al., 2001).

It has been shown that gains in FCI scores can be accomplished by "interactive engagement" instructional methods, as documented by Hake (1998). In order for instructors to use a "modeling" method of instruction, necessary elements should include:

1) *Subject competence,* essential to teacher effectiveness.

2) Proficiency in *scientific inquiry* (more important than specific content knowledge). Beyond a minimal background of a few physics courses, teaching effectiveness depends only weakly on the extent of academic physics training.

3) Managing *the quality of classroom discourse* is one of the most important factors in teaching with interactive engagement methods. Effective discourse management requires careful planning and preparation as well as skill and experience.

4) Creating an instructional environment where students *construct their own meaning and understanding*.

6) Technical knowledge about teaching and learning is as essential as subject content knowledge (Redish, Steinberg & Wittmann, 2002).

Few teachers can acquire the necessary skills without explicit instruction in a strong program of professional development. G*ood teaching* is a skill that can be learned and great teachers are great learners who love to share (Redish et al., 2001). Steinberg and Sabella (1997) provided further evidence that student understanding of the force concept is often incoherent.

Hake (2001) states that “so great is the inertia of the educational establishment that three decades of physics-education research demonstrating the futility of the passive-student lecture in introductory courses were ignored until high-quality standardized tests that could easily be administered to thousands of students became available.”

Good teaching is based on an ongoing *dialogue* between teacher and students, in which both parties are able to understand the other’s point of view (Scott, 1998). The very conception and design of the FCI can help the teacher to come to know and to understand the fundamental concepts of interactive instruction (in terms of both conceptual learning goals and student misconceptions) to be in the position to *sustain* effective teaching and learning techniques. The FCI provides a tool not only for improving student learning but also for improving the instructors' understanding and approaches to teaching in physics (Redish et al., 2002).

Course Grades

As an additional and overall measure of student success in the introductory calculus-based physics course, final course grades were examined. Because all students, treatment and control groups for each of the three professors’ students included in this study, had the same requirements, except for the treatment administered to the treatment group, these final grades were used. Since three professors and their students participated, using non-standard tests, throughout the semester, course examinations and tests were not used for assessment.

It is important to know what kind of sustained effect that GTAs teaching had on the way students thought about force and motion. Did the explicitly modeled interactive engagement instruction of GTAs encourage students to learn physics better? And, since the grading scales were uniform for course grades and treatment as well as control groups were included, the final course grades were used as an additional assessment tool.

Qualitative Measures

For Research Question 1: GTAs' Adherence to ***EMIT*** *Model*

Flash Mediated Assessment (FM2CA)

One assessment used in this study to track the effects of GTA interactive-engagement instructional techniques on student success, Flash-mediated interactive simulations of force and motion scenarios were used as formative assessments. These simulations were designed as problem-based scenarios.

Animations have been found to often increase the validity of questions since they tend to diminish the effect of a confounding variable (Dancy, 2000). In written assessments, students do not always answer the question being asked because they may understand the question. Dancy (2000) found that in these cases animation cleared up the misunderstandings. Her research also found that:

- Animation was most likely to have an effect when a question involves motion and understanding the animation was central to answering the question
- Performance on animated questions was less linked to verbal ability.
- Animations can reduce question misunderstandings, making them a more valid measure.

Williams, Pedersen & Liu (1998), found that students who were exposed to an online Problem-based Learning environment showed greater gains on achievement scores pre to posttest compared to students who learned the same content in the traditional classroom. Another study supporting this conclusion include Constructing Physics Understanding (2003).

Pre-Post Semi-structured Interviews

A semi-structured interview was carried out with each GTA as they instructed introductory physics students during recitation. This was in order to attempt to verify some of the observational data and add the benefit of “thick description” by obtaining information, which could not be collected reliably through observation. During the interview, each GTA was asked the same series of questions about any experience with physics and physics teaching (Geertz, 1973).

Student Survey Comments

In reformed classrooms “students explain and justify their work to themselves and to one another” (National Research Council, 1995, pg. 33).

They "assess the efficacy of their efforts—they evaluate the data they have collected, re-examining or collecting more if necessary, and making statements about the generalizability of their findings. They plan and make presentations to the rest of the class about their work and accept and react to the constructive criticism of others."

In this study, design of the Student Survey (patterned after the RTOP instrument) included both a Likert scale and student comment section. From the student comments, qualitative evidence of GTA adherence to the interactive-engagement (**EMIT**) model was derived.

For Research Question 2: GTAs' Understanding of the Nature of Physics

MPEX2 Part II

The latest version of the MPEX2 instrument (used for GTAs in this study) included free-response items and justification of answer choices. From the choices made, qualitative assessment of GTA beliefs about the nature of physics could be surmised.

Video Observation Comments

During analysis of the videotaped observations, student and GTA comments were transcribed and categorized. Samples of GTA and student comments provide evidence for an assessment of maturation of understanding about the nature of physics and physics teaching by GTAs in this study.

Visual Physics CPQ Problem #8

You are worried that bad physics is being taught to children in the movies. So, you have joined a committee that reviews the Spiderman 2 Movie. Spiderman is on the ground in front of a menacing Dr. Otto Octavius.
Just in time Mary Jane (50 Kg), who is above him (original height = 30 m) on a fire escape, sees him. She grabs a TV cable (attached 20 meters directly above Spidey on a catwalk) and swings towards Spidey, who is twice her mass, to save him. Luckily, the lowest point of her swing is just where Spidey is standing (2 m above the ground). When she reaches him, he grabs her and they both continue to swing to safety over Dr. Octavius' head.

a) In order to approve this movie, the physics must be correct, so you calculate the maximum height Spiderman and Mary Jane can swing as a fraction of her initial height.
b) Calculate MJ's velocity at the bottom of her swing.
c) Calculate their velocity just after she grabs Spidey.
d) Calculate the maximum force on her arms, as she grabs Spidey

SASD: Be sure to write down ALL of your assumptions, sketch (w/ Free Body Diagrams, if appropriate) and show how you derive the formulas. Box Answers.

Figure 11 Example Visual Physics CPQ for Recitation

For Research Question 3: Student Evidence of Conceptual Change

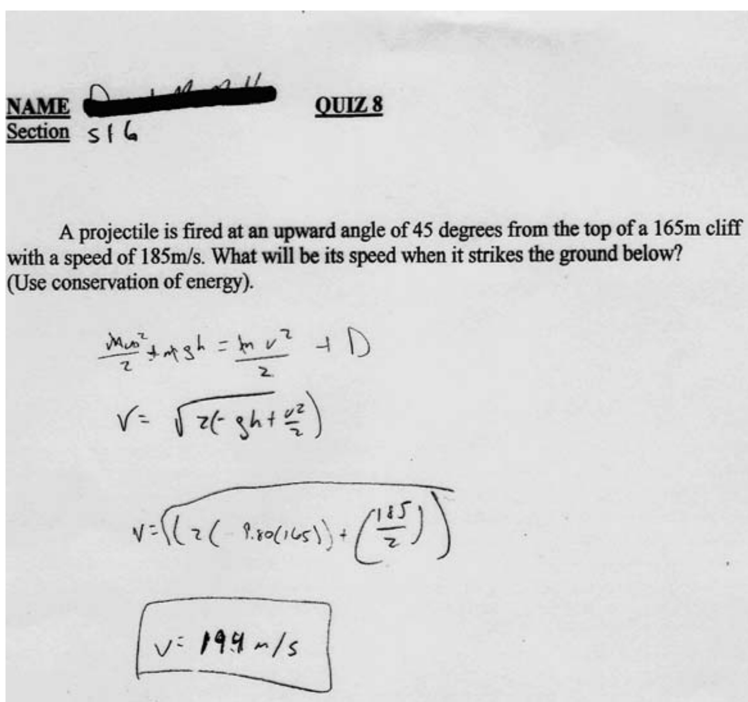
Cooperative Group Problems (CPQs)

Students in introductory physics courses typically begin to solve a problem by searching for and manipulating equations, plugging numbers into the equations and ignoring any conceptual perspective until they find a combination that yields an answer. These novices rarely plan a path to their solution before plunging into numerical and algebraic manipulations of equations. After they arrive at an answer they rarely check to see if it makes sense (Heller, et al., 1992). An example concept-rich problem scenario can be seen in Figure 11.

Initially, many students do not understand or appreciate the dynamics of working in cooperative groups, especially since they have been trained to be competitive and work individually. Lacking the necessary collaborative skills, students need to be explicitly taught how to productively and cooperatively work together (Heller & Hollabaugh, 1992). Qualitative measures of student performance in response to the graduate teaching assistants' instruction included video analysis of the problem-solving scenarios as well as text analysis of online simulations.

Traditional Recitation Problems

Traditional recitation problems emulate those given as homework. A student sample can be seen in Figure 12.



NAME [redacted] **QUIZ 8**
Section 516

A projectile is fired at an upward angle of 45 degrees from the top of a 165m cliff with a speed of 185m/s. What will be its speed when it strikes the ground below? (Use conservation of energy).

$$\frac{mv_0^2}{2} + mgh = \frac{mv^2}{2} + D$$

$$v = \sqrt{2(-gh + \frac{v^2}{2})}$$

$$v = \sqrt{(2(-9.80(165)) + (\frac{185}{2}))}$$

$$\boxed{v = 194\ m/s}$$

Figure 12 Worked Student Example of a Traditional Recitation Problem

Methodology: Research Design

The Non-Equivalent Groups Design (NEGD) is one of the most frequently used designs in educational research. It is based on a pretest-posttest randomized experiment but without random assignment (Trochim & Land, 2002). In the NEGD, similar intact groups are selected as the treatment and control groups. Often two comparable classrooms are used in educational research. According to Trochim (2003), this just means that assignment to group was not random. A student profile and baseline math skills for physics data was gathered to further reinforce the homogeneity-of-groups contention.

Since mixed methods have demonstrated complementarity in providing breadth and multiple representations of data, undergraduate students were assessed primarily by quantitative methods (Van Heuvelen, 1997; Giere, personal communication, 2003; Creswell, 2003). These measures included the Force Concept Inventory (FCI), Student Survey, and the Flash-mediated Force and Motion Concept Assessment (FM^{2}CA). Both treatment (VP) and control (TR) sections were observed and field notes were taken, including using the RTOP assessment of graduate teaching assistant methodology, encompassing the elements of modeling and interactivity explicitly addressed during instruction.

All quasi-experimentation is judgmental. It is based on multiple and varied sources of evidence, it should be multiplistic in realization, it must attend to process as well as to outcome, it is better off when theory-driven, and it leads ultimately to multiple analyses that attempt to bracket the program effect within some reasonable range (Trochim, 2004).

Role of Statistics in This Study

In this study, descriptive statistics are used to describe the basic features of the data and to give a basis of comparison between treatment (VP) and control (TR) groups, summarizing the data into tables and figures. The use of univariate analysis involves the examination of all of the cases of each variable used to measure GTA performance, in order to gain an understanding of each graduate teaching assistant's success in applying the lessons learned.

Three major characteristics of each variable are examined: 1) distribution, expressed in percentages, 2) the central tendency, the mean and 3) the dispersion, the standard deviation. Using inferential statistics, the observed differences between each graduate teaching assistant's data is examined and explained.

Multivariate analyses on the FCI, Student Survey and Final Course Grades obtained in this study, was undertaken in order to assess the consistency of the impact (on the GTA and student) of the GTA instruction in interactive-engagement methods and application during recitation. Effect size was also calculated to assess not only statistical but also practical significance, using Cohen's d and Hake's <g> (Thompson, 2002; Hake, 1998). In addition, these data were analyzed for generalizability to a wider population and compared with results of similar studies. Discriminate Function Analysis utilized grouping of several measures to examine impact of GTA methods on the change in student performance. The three scores used were the: 1) Force Concept Inventory, 2) score differences on the Student Survey of GTA performance between week 1 and week 14, as well as 3) Final Course Grades.

Exam results were not compared as they were constructed independently by each professor and varied from exam to exam with one of the professors even varying his exam style for each of the four exams. In order to examine the external validity (generalizability) of the results from the student sample, sampling of student FCI pre and posttests was done across several groups of GTAs' students. The relationship to a larger population of Physics 218 students was examined in order to assess the impact on student conceptual understanding of the instructional model (EMIT) used by treatment GTAs.

A continuum can be constructed of the ratio of *generalization of results* to total *specification of results* in quasi-experimental research (Campbell & Stanley, 1963). Since causality is not claimed for this study, *correlation* between variables was attempted on several measures across graduate teaching assistants' and their students. In order to eliminate as much bias as possible, correlation of the population to the sample in key characteristics was also done on several measures in order to achieve an optimum of generalizability.

Descriptive techniques with in-depth descriptions of the graduate teaching assistants and their sections were drawn in order to establish equivalency, normalcy and a fuller perspective as well as context of the sample selected (Geertz, 1973).

Methodology: Research Question 1

GTA Instructional Model: EMIT

The goal of the graduate assistant instruction is to synthesize an effective interactive recitation environment through which the application of cognitive coaching methodology by treatment GTAs could result in more expert-like problem solving by students. This synthesis culminated in the explicitly modeled interactive-engagement techniques (EMIT) organized around explicit modeling scenarios using RTOP and other materials. The schedule and elements of the EMIT model, used during the GTA instruction prior to the Fall Semester, 2003 can be seen in Appendix B.

Description of the EMIT Model

Initially, graduate teaching assistants attended a week long intensive instruction that modeled the methods for 1) conducting interactive-engagement teaching; 2) detecting and acknowledging prior naïve conceptions about basic physics principles held by students; 3) instituting cooperative group problem solving; 4) posing Socratic and elicitation questioning; 5) creating and applying context-rich problem scenarios and 6) acting as cognitive apprentices during instruction. Control GTAs were interviewed tested and observed with the same instruments. The only difference was that the control GTAs did not receive instruction and did not use the instruction materials. In Table 9, the elements of the EMIT model and their suggested applications are shown.

Table 9 *The EMIT Model: Delineated*

Actions	Pre- Instruction	During Instruction	Formatively During Semester
Trainer/ Instructor	Modeling Methods of: • Socratic Questioning, • Cognitive Coaching ("scaffolding and fading" methods) and • Just-in-Time Intervention **FOR** GTAs • Measured by RTOP		• Revisiting of Methods and acquired Skills • Readings' discussion and detailing of problems, as arise. • Formulation of Action Plan
GTA		Modeling Above Methods **BY** GTAs **FOR** students	• Modified Recitation Instruction **BY** GTAs **FOR** Students
Student		Initial Solution Model building through: • Interactivity between GTA and Student with • Cooperative Group Problem Solving **BY** Students	Improved Skills at Teaming, Model-building and Problem Solving

In Figure 13, an overview and timeline for this study is shown. A day-by-day description follows.

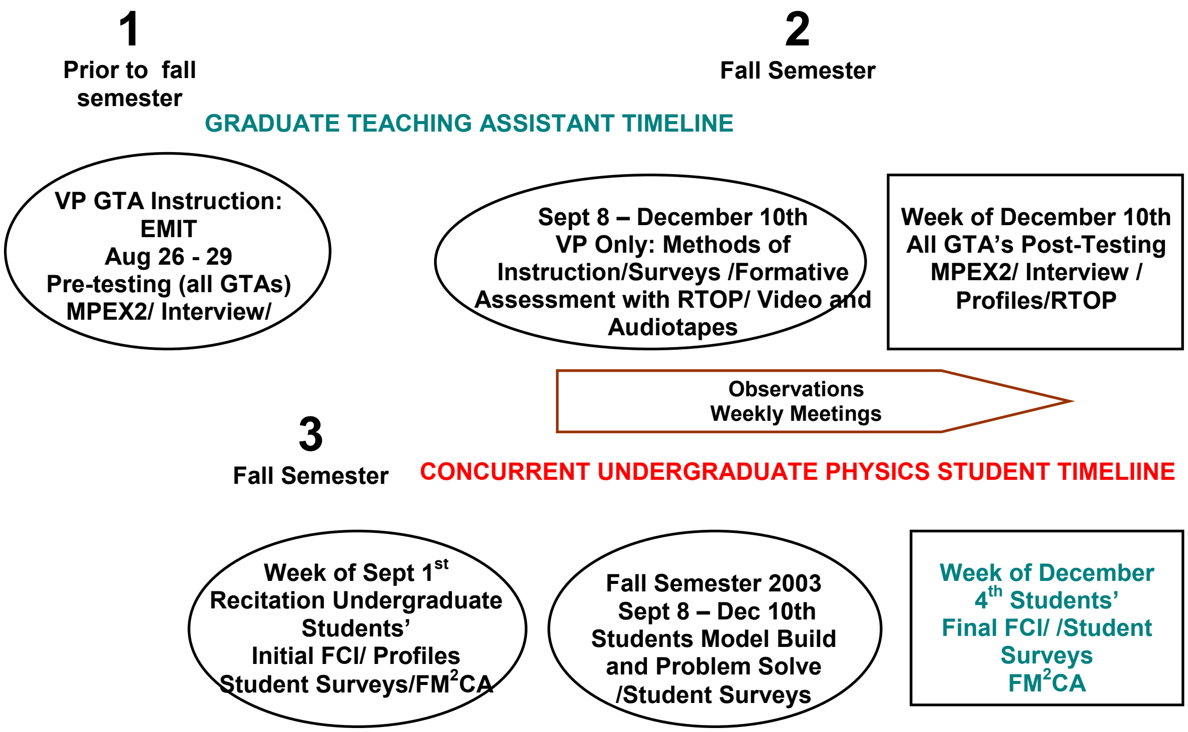


Figure 13 Overview and Timeline of Procedures

On the first day of the instruction week, treatment graduate teaching assistants were assessed and interviewed using: 1) the Maryland Physics Expectations Survey 2 (MPEX2), 2) *Diagnoser*, testing GTA understanding of physics concepts, through the online assessment (Hunt & Minstrell, 1994), 3) semi-structured interviews 4) student problem solving examples with interactive discussions and 5) the Force Concept Inventory (FCI), the conceptual measure that students would be pre and post tested on. See Appendix C for a copy of the FCI instrument.

Graduate teaching assistants were also introduced to the RTOP (Reformed Teaching Observation Protocol) that would be used in evaluating their teaching during the semester by the researcher. A heuristic, designed by the researcher to show the relative amount of instructional “force” needed to explicitly model these methods, compared to the output “force” of internalization by treatment GTAs, during each day of the instruction week.

On the Second Day, the graduate teaching assistants were immersed in the processes of observing, emulating and evaluating explicit examples of excellent, average and poor interactive engagement, and student-centered instruction, provided on the RTOP web site and on videotape, delineating the reformed physics teaching elements of instruction (MacIsaac & Falconer, 2002). GTAs rated the teaching and negotiated consensus on scores, through discussion and coaching by the researcher, then between themselves, in groups of three, emulating strategies that they would later implement during recitation with undergraduate students. Graduate teaching assistants then read research articles on Socratic questioning and elicitation techniques (Minstrell, 2001; Hake, 1998). Discussions about discourse management and misconnects were held. See Appendix D for a copy of the Student Survey of recitation.

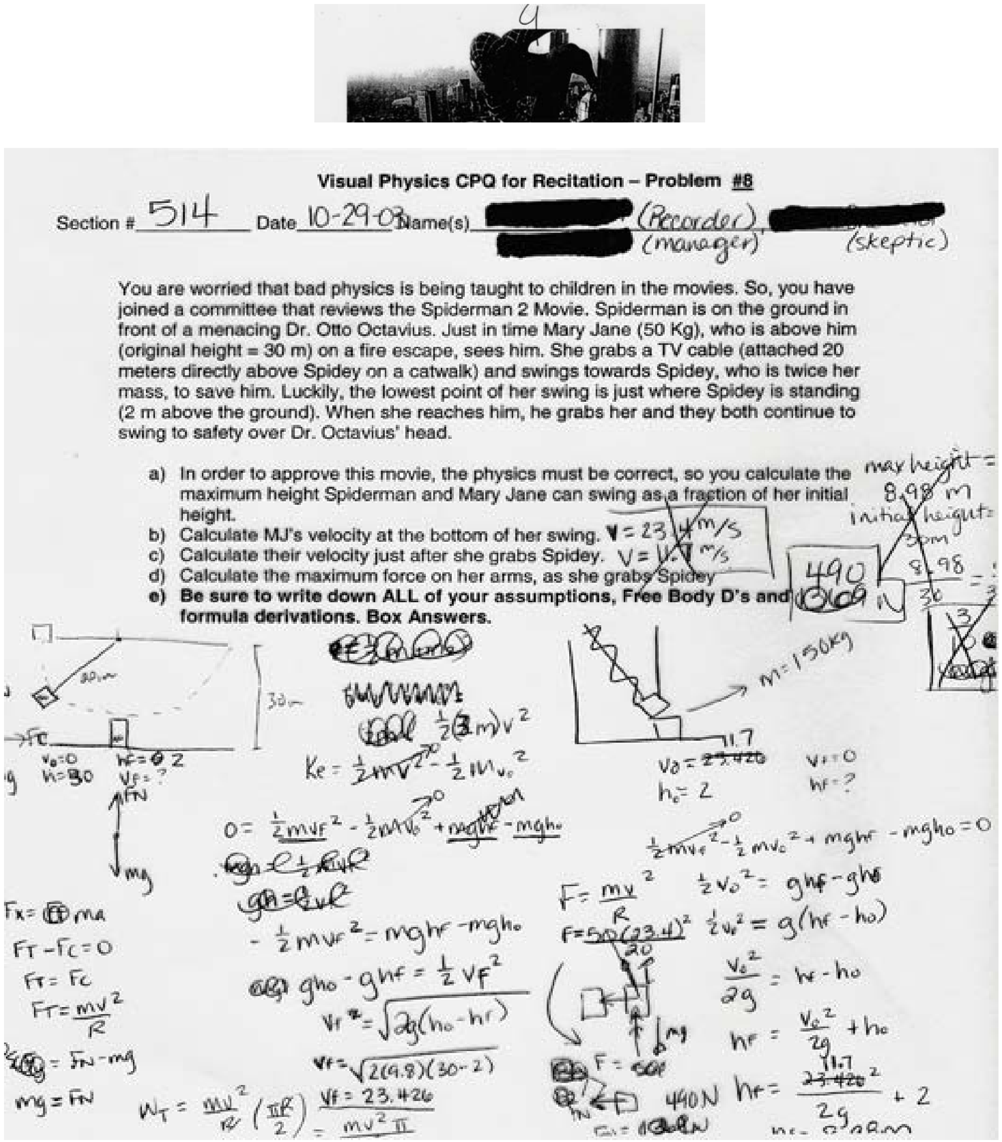
Negotiation of scores and discussions of desirable methods and their rationales also were an integral part of this explicit instruction. Methods of detecting, acknowledging and addressing student naïve conceptions about fundamental physics concepts were also addressed and discussed (Hestenes &

Halloun, 1995; Elby, 1999). Just-in-time intervention techniques and cognitive coaching strategies were read about, discussed and practiced (Roschelle, 1995; Novak, et al, 1999).

On the Third Day, examples of context-rich physics problems continued to be analyzed, constructed and discussed. GTAs created mock lessons and evaluated each other, and themselves, using the Reformed Teaching Observation Protocol (RTOP) instrument. They were also introduced to a related instrument, the Student Survey, derived by the Researcher from and scaled similarly to the RTOP. Graduate teaching assistants began to modify traditional problems, applying them to real-world situations, folding in the five elements of a good context-rich problem (Heller & Heller, 1995). For a description of these elements, see Appendix D.

These context-rich problems evolved into a model for the Concept Problem Quizzes (CPQs), applied later in student cooperative group scenarios, coached and guided by the graduate teaching assistants. An example of a student-worked concept-rich quiz can be seen in Figure 14.

Graduate teaching assistants learned the tools needed in order to guide students as they built solution models of the CPQs that folded in multiple representations of the scenarios (Van Heuvelen, 1991b). Research in the area of novice student learning was sampled and discussed (Mestre et al., 1993; Hunt & Minstrell, 1994).



Visual Physics CPQ for Recitation – Problem #8

Section # 514 Date 10-29-03 Name(s) [redacted] (Recorder), [redacted] (manager) (skeptic)

You are worried that bad physics is being taught to children in the movies. So, you have joined a committee that reviews the Spiderman 2 Movie. Spiderman is on the ground in front of a menacing Dr. Otto Octavius. Just in time Mary Jane (50 Kg), who is above him (original height = 30 m) on a fire escape, sees him. She grabs a TV cable (attached 20 meters directly above Spidey on a catwalk) and swings towards Spidey, who is twice her mass, to save him. Luckily, the lowest point of her swing is just where Spidey is standing (2 m above the ground). When she reaches him, he grabs her and they both continue to swing to safety over Dr. Octavius' head.

a) In order to approve this movie, the physics must be correct, so you calculate the maximum height Spiderman and Mary Jane can swing as a fraction of her initial height.
b) Calculate MJ's velocity at the bottom of her swing.
c) Calculate their velocity just after she grabs Spidey.
d) Calculate the maximum force on her arms, as she grabs Spidey
e) **Be sure to write down ALL of your assumptions, Free Body D's and formula derivations. Box Answers.**

Figure 14 Example of Student-worked Concept-rich Quiz

Practice with all methods during instruction and subsequently during the semester, and weekly meetings reinforced the strategies and methodologies learned during instruction.

On the fourth day, both the formative assessments of graduate teaching assistants' application of methodologies and their students' problem-solving scenarios and direct interactions were discussed. Strategies for 1) managing instruction, 2) guiding student instruction during recitation, 4) managing and critiquing the online simulation formative assessments (FM^2CA) and 5) assessing the solution models for context-rich problems was also discussed and applied.

The practice of scaffolding and fading within the Cognitive Apprenticeship model (Collins, et al, 1991) was revisited and strategies planned for this practice.

Quantitative Measures

The RTOP Instrument

The researcher was trained on the use of the assessment instruments used by MacIsaac & Falconer (2002). Instructional videos were subsequently used in the GTA instruction and viewed on the Reformed Teaching Observation Protocol (RTOP) web site. (http://www.ecept.net/purcell/RTOP_full/index.htm).

All GTAs' instruction was observed and evaluated by the researcher, using the RTOP at weeks 1, 7 and 14. The observations were videotaped and field notes were taken. Scores were tabulated for all GTAs. Analysis of these data was performed using descriptive statistics and graphed. Videotapes were analyzed and compared, using assessments of interactive teaching underpinning the RTOP for which inter-rater reliability was calculated by comparison with the researcher's original scores.

The Student Survey

Students in the treatment group were asked to respond to the format, instructional environment and cooperative group problem-solving methods used during an 18-item survey whose items corresponded one-to-one with the GTA evaluation instrument (RTOP), used by the researcher to assess the interactive nature of the instruction for GTAs. The week 1, 7 and 14 scores were calculated and became one of the three criteria for the Discriminant Function analysis, whose other criteria were student FCI post instructional scores and students' final course grades.

The scores used reflect 1) the degree to which GTAs adhered to the Cognitive Coaching model as measured by the RTOP (researcher applied) and Student Surveys (students were surveyed about their recitation experience, 2) degree to which students experienced conceptual change on the Force Concept Inventory Instrument (FCI) and 3) were reflected in the final course grades of students. Effect sizes were measured two ways, using Cohen's d and Hake's g.

Discriminant Function Analysis (DFA)

Discriminant Function Analysis was used as one measure of characteristics of group measurement and since prior differences between the groups could affect the outcome of the study, care was taken to evaluate graduate teaching assistants and their student scores on the basis of several indicators: 1) multivariate normal distribution for each sample from the population; 2) population variances and dependent variables uniform across all levels of the factor; and 3) the samples were selected from the population studied and the scores on each variable for any one participant was independent of the scores on all other variables (Grimm & Yarnold, 2003). A 2-level DFA was initially run in anticipation of a highlighting of group differences between treatment and control student scores.

Table 10 delineates the quantitative data sources for the graduate teaching assistants and the measures that garnered these data. Graduate teaching assistants also were tested on the MPEX2, for understanding of the nature of physics and on the RTOP for assessment of teaching performance.

Table 10 *Descriptions of GTA Quantitative Data Sources (Description of Criterion Variables for the DFA Analysis)*

Instruments **Treatment (VP) Group** **Control (TR) Group**	**Function 1**	**Description**
Pre-Assessments	**FCI**	Force Concept Inventory – administered Pre and Post instruction
Formative for the GTA for Revisions of Coaching in Recitation	**Student Surveys**	Student views of how GTAs taught during recitation. Validated instrument, based on RTOP.
Summative	**FCI**	Force Concept Inventory – administered Pre and Post instruction
	Final Grades	Final course grades

The student scores on the FCI, Student Survey and final Course Grades were combined as criterion variables in a DFA test in order to ascertain if GTA adherence to the EMIT model produced an effect on student performance and fundamental conceptions of force and motion in the calculus-based physics course.

Qualitative Measures

Table 11 displays the GTA Qualitative Data Sources. The interviews were given both at the beginning and the end of the Fall Semester, 2003. GTAs made comments and decisions on the MPEX2, part II about their views of teaching and physics problem solving. Video taken during GTA instruction captured instructional decisions made that reflected further on GTA beliefs about physics and physics teaching.

Table 11 *Descriptions of GTA Qualitative Data Sources*

Instruments **Treatment (VP) Group** **Control (TR) Group**	**RQ**	**Measure**	**Description**
Pre- Assessments	1,2	Semi-structured Interviews	Pre and Post interviews with the graduate teaching assistants in both groups
	2	MPEX2 Part II	Maryland Physics Expectation Survey measure the GTAs' understanding of the Nature of Physics
Formative for the Researcher for Revisions to the Model	2	MPEX2 Part II	Maryland Physics Expectation Survey measure the GTAs' understanding of the Nature of Physics
	1	Recitation Video Analysis	Coded and Analyzed Video of GTA Instruction for both groups
Summative	1,2	Semi-structured Interviews	Pre and Post interviews with the graduate teaching assistants in both groups
	1,2	MPEX2 Part II	Maryland Physics Expectation Survey measure the GTAs' understanding of the Nature of Physics

Pre-Post Semi-structured Interviews

GTAs were interviewed during the instructional week, prior to the Fall Semester, 2003 and again at the end of the semester using a semi-structured interview instrument. This instrument was derived from questions on the MPEX2 concerning the nature of physics and physics teaching. The interview instrument also gathered background information about the GTA and included their general experiences with physics education. See example questions in Table 12. These ten interview questions were derived from the MPEX2 instrument, for the copy of that instrument, see Appendix F.

Table 12 *Examples of Semi-structured Interview Questions*

Question Posed
Q4: What prompted you to teach physics?
Q6: How effective have your own physics teachers/professors been in teaching physics?
Q7: How would you model or change the physics teaching you have seen?
Q10: What are the most important elements of teaching physics effectively?

Student Survey Comments

The Student Survey also included opportunity for open-ended student comments about the structure of the instruction during recitation and impressions about their experiences. This survey was derived from items on the RTOP and has one-to-one correspondence with those items. The scale used was the same as on the RTOP and analysis was done, using the same methods. Video and field notes also captured and documented student comments and expressions. These qualitative data were used to support the contention that treatment GTAs adhered to the EMIT model. These comments were sampled and scores compiled. Student Surveys were administered at weeks 1, 7 and 14 during the recitation sections for both treatment and control groups.

Methodology: Research Question 2

GTA Nature of Physics Understanding

Methods used to arrive at assessment of GTA understanding of the nature of physics were multi-fold. Both quantitative and qualitative measures were used. Interviews, video observations, scores on the MPEX2, part I and GTA comments on the MPEX2, part II, and field notes round out the means of data collection. Methods of applying these instruments are delineated below.

Description of the Nature of Physics

GTA understanding of the nature of physics and the nature of physics teaching is pivotal to their adherence to the **EMIT** model of reformed teaching. Although most physicists believe that deriving models of the real world is necessary to experimentation in physics, students do not automatically make that connection (Saul, 1997). GTAs bridge a role between that of physicists and students.

Acting as content experts in the role of cognitive coaches, the treatment GTAs understandings of the nature of physics impacted their student's thinking during problem solving. GTAs answered student questions, guided inquiry and scaffolded student attempts at solving context-rich problem scenarios in cooperative groups.

Quantitative Measures

MPEX2 Part I

Part one of the MPEX2 instrument was given to all study GTAs pre and post semester at weeks 1, 7 and 14. Analysis of these data was done using descriptive statistics, and these data were graphed in an attempt to track a change in GTAs' conceptions about the nature of physics and physics problem solving. The MPEX2 is a measure of expectation and belief about physics and physics teaching.

Qualitative Measures

MPEX2 Part II

GTA comments and choices made in discriminating between actions they would take, given several teaching situations, reflect their beliefs about the nature of physics and physics teaching. Results were tabulated and checked against the national data as further evidence of maturation and change.

Video Observation Comments by GTAs

GTAs in both treatment and control groups gave feedback during recitation observations throughout the semester. Treatment GTAs gave feedback daily, during the week prior to the Fall Semester, 2003 as well as during weekly meetings. These comments were captured in field notes, interview forms and on videotape. . The GTAs' conceptual understandings, the maturity of their understanding of the nature of physics and physics problem solving as well as their application of the EMIT model were reflected in comments they made, throughout the semester.

Methodology: Research Question 3

Students' Conceptual Understanding of Force and Motion

For the undergraduate students, quantitative data sources were derived from pre and post FCI tests along with formative assessments via the web-based formative assessment, the FM^2CA.

Description of Student Conceptual Understanding

Attempts to reveal student conceptual understanding were based on both qualitative and quantitative measures carried out during recitation by GTAs.

Quantitative Measures

Sources of quantitative data for all students in this study were the FCI, (pre and post applications were given); the graded concept problem quizzes, Student Surveys and final course grades were measured against the larger population for both treatment and controls. See Table 13 for a description of the quantitative assessments used for students. Analysis of these data was accomplished using descriptive and inferential (DFA) statistical tools.

Table 13 *Descriptions of Student Quantitative Data Sources*

Instruments Treatment (VP) Group Control (TR) Group	Measure	Description
Pre-Assessments	**FCI**	Force Concept Inventory – administered Pre and Post instruction
Formative for the Student as they gained skill in solving content-rich problems	**CPQs**	Weekly content-rich problem scenarios
Summative	**FCI**	Force Concept Inventory – administered Pre and Post instruction
	Final Grades	Final course grades

Force Concept Inventory

The FCI was administered in the first week of the semester and at the end of the 14th week. Data were gathered for all study sections, compiled and compared. Analysis of these data was done using descriptive methods (mean, standard deviation) and comparison graphs were constructed. An inferential statistical test was run – the Discriminant Function Analysis (DFA). The post FCI test was one of the criterion variables in that test.

Course Grades

At the end of the semester, course grades were gathered for all students in the study and compared against course grades for Physics 218 for the past three years. These data were used as one of the criterion variables in the DFA test.

Recitation Interactions

The videotape methodology included observations of all GTAs' instruction, at weeks 1, 7 and 14. Especially sampled were student interactions and interactions between GTAs and their students during problem solving scenarios in recitation. The frequency of interaction, type of interaction (reformed or traditional as per the RTOP instrument definitions) along with transcripts of student-to-student and GTA-to-student dialogues was sampled. Included in the field notes, taken at the time of taping was physical arrangement of the room, mapping of the position of the video camera and number of the student group being observed. Description of all GTA actions, during observations and student reactions was also chronicled.

Qualitative Measures

Qualitative student measures include analysis of the recitation videos and the visual physics problem-solving scenarios (Concept Problem Quizzes) as indicated in Table 14. Elements of the interactive materials and formative assessments were included in the online materials offered through the WebCT site for the course – the Flash-mediated Force and Motion Conceptual Assessment (FM^2CA). Undergraduate physics students were tested during the first week of the semester during their recitation section and online through the WebCT site.

Table 14 *Descriptions of Student Qualitative Data Sources*

Instruments **Treatment (VP) Group** **Control (TR) Group**	**Measure**	**Description**
Pre-Assessments	Student Profiles	Background information on students
Periodic	Video Analysis	Coding of interactive problem-solving scenarios during video taping
	FM2CA	Online Simulations of real world phenomena. Students are asked to solve and justify.
Summative	Student Survey Comments	

FM2CA

Web-based physics simulations, when incorporated into a well-established interactive instructional design, have also been shown to enhance students' understanding of basic concepts (Van Heuvelen, 1990; Roschelle, 1991; Pedersen & Liu, 2003). Further, web-based interactive methods can involve the student in choice making about the nature of physics phenomena and the motions that exemplify them (Beichner, 1996; Dancy, 2000; Allen, 2003). Initially, two online simulations were given to all students in the study, treatment as well as control, and acted as instrument training and practice. Subsequently three simulations were assigned to all students over the course of the semester, roughly at weeks 1, 7, and 14. The simulations animated three motion and force experiments similar to those that students performed in the lab part of the course. After being given rudimentary information about expectation, students interacted with the simulations, answering questions about the motion and/or forces shown and accessing information. These data were preserved and subsequently analyzed for: 1) correct physical explanation, 2) evidence of conceptual understanding and 3) change in conceptual understanding from the previous assessment (Allen, 2003).

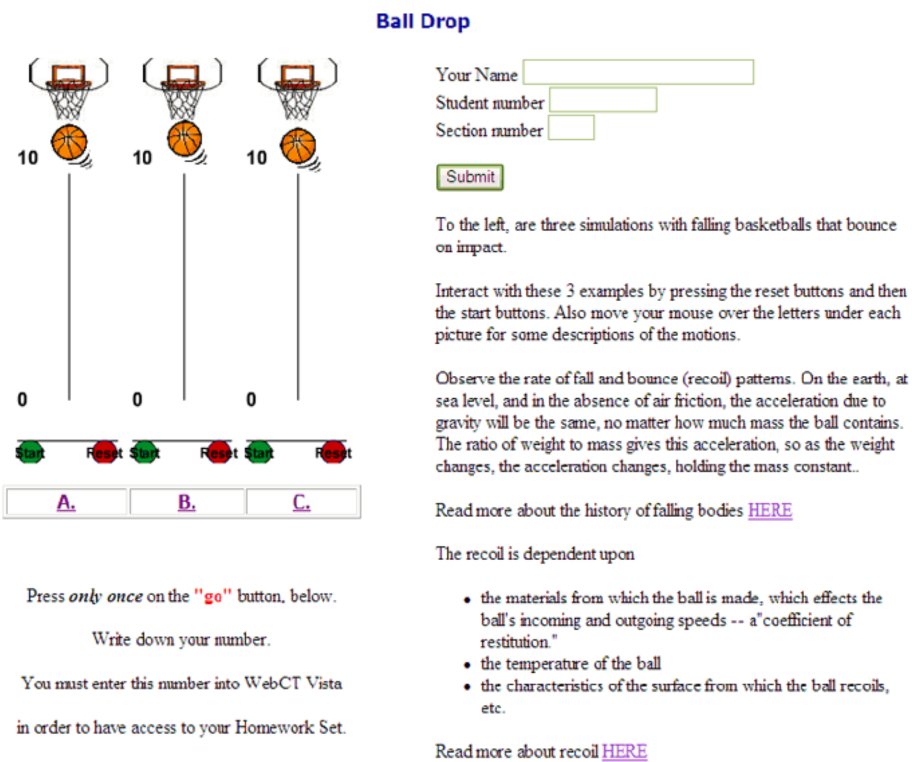


Figure 15 Example Interactive Simulations

The Flash-Mediated Force and Motion Conceptual Assessment, created for the students in this study, is just such a formative assessment. See Figure 15 for an example FM2CA actually used in recitation during the semester. Students are involved in defining and interacting with basic concepts of force and motion, integrated into physics scenarios accessed online with applications to the real world of the physics phenomena under study. During this process students are asked to justify their choices in text form.

Cooperative Group Problems (CPQs) (VP)

The gap between the views of instructors and students can reveal a mismatch between student expectations and instructional design. Students may believe that physics has little or no relevance to their personal experience. GTA instruction needs to explicitly address this problem. Students who do develop a good conceptual understanding of physics will need to reconcile what they learn with what they thought they knew about how things work in the physical world. Even students who come into an introductory physics class with a more-physics like view find new applications and subtleties that help them see the world in new ways (Saul, 1997). Students in the treatment group in this study were encouraged to interact with each other and the GTA in a cooperative setting, while solving concept-rich problems. The setting was one in which the student (novice) worked in pre-defined roles (skeptic, manager, recorder) to solve a problem too complex for any one of them to solve individually. In modeling the problem solutions, students were "coached" by the GTA (content expert), as they needed hints to progress. GTA provided scaffolding (support) and fading (removing support) which gradually took place over the semester as students gained expertise.

Traditional Recitation Problems (TR)

For the control sections, homework problems were worked by the GTA on the board in the front of the classroom and the students watched, asking occasional questions. Interaction between students and GTAs was assessed.

Summary

In this study the GTA instructional model (EMIT) and the attendant measurement instruments were designed to reveal the extent to which the physics graduate teaching assistants were able to 1) internalize, construct and express mature views of the nature of physics and methods of teaching problem-solving 2) externalize interactive-engagement methods as they coached undergraduate physics students, guiding them toward more expert practice; 3) impact undergraduate physics students’ cooperative group problem solving performance, moving them from novice to a more expert practice; and 4) enhance their conceptual understanding of fundamental physics principles. Student performance, in the recitation and in the course as a whole, provided the data to investigate the impact of the graduate teaching assistants’ instruction. Focus on the results of the qualitative and quantitative analyses in the next chapter will reveal correlations and patterns between the data, as well as evidence for the graduate teaching assistants’ individual impact on students’ performance during applications of the interactive-engagement methods that make up the EMIT model.

CHAPTER IV

RESEARCH FINDINGS

> To suppose that scientific findings decide the value of educational undertakings is to reverse the real case. Actual activities in educating test the worth of the results of scientific results. They may be scientific in some other field, but not in education until they serve educational purposes, and whether they really serve or not can be found out only in practice.
>
> − John Dewey

Research Questions

1. To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?
2. What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?
3. What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Introduction

This chapter highlights the quantitative and qualitative results from the instruments used to examine each of the three research questions proposed for this study. The impact of the explicitly modeled interactive-engagement techniques (EMIT**)** model used in GTA instruction is also examined. The data are organized around the research questions posed to show the degree to which physics graduate teaching assistants 1) adhered to methods learned, 2) changed their views about the nature of physics and the problem solving process and 3) positively impacted students' problem solving performance. Individual GTA data are examined in order to assess the success of the treatment. Evidence gathered by tracking changes in student scores provides a glimpse into the interactions transpiring during recitation for each GTA.

In the control group, graduate teaching assistants' were observed as they taught using the traditional problem solving (mostly lecture format) methods that were typical for this course. The data are summarized through descriptive and inferential quantitative measures as well as qualitative measures. The qualitative measures applied were profiles, interviews, and students' problem solving products and sampled video transcriptions. The results are organized around elements of "reformed teaching" defined by the RTOP and Student Survey instruments as well as established by the reformed teaching literature. See Chapter II for a discussion of the research behind reformed physics teaching.

Descriptive statistics are used to look at the basic features of the data and to give a basis of comparison between treatment (VP) and control (TR) groups, summarizing the data into tables and figures. Three major characteristics of each variable were examined: 1) distribution, expressed in percentages, 2) the central tendency, the mean and 3) the dispersion, the standard deviation.

Research question one was addressed, using Discriminant Function Analysis. The two-level Discriminate Function Analysis revealed control and treatment group differences as evidenced by student scores on the 1) Force

Concept Inventory, 2) Student Survey assessing GTA performance between observation 1 and observation 14, as well as 3) Final Course Grades.

Originally the DFA was chosen to measure treatment GTA adherence to the EMIT model, compared to the control group GTAs. However, when a 4-level DFA was run, using each individual GTA's student scores, a less clear difference between treatment and control was seen. In fact, although differences between GTA groups were evidenced in the data from tests of effect size and other sources, some evidence showed that some of the outcomes may be due more to individual GTA differences rather than the treatment itself.

Effect size for these data was calculated in an attempt to assess the effect of the intervention in student scores from the treatment and control groups as well as differences in GTAs' recitation performance in each group. Examining effect size can reveal if a treatment had an impact compared to a control group. Statistical test of effect size used in this study can show "practical significance" and is determined by using Cohen's d and Hake's <g> (Thompson, 2002; Hake, 1998). In addition, these data were analyzed for generalizability to a wider population and compared with results of similar studies.

Before beginning the following descriptions, it might be useful to examine Appendix G where research questions are organized in a table with the accompanying instruments used to measure the results.

Research Question 1

To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?

Quantitative Results

The quantitative measures whose data support treatment GTA adherence to the reformed teaching model are: 1) the RTOP, 2) the Student Survey, 3) RTOP comments, 4) student comments, 5) Discriminant Function Analysis and 6) GTA interview comments. The treatment group's GTAs were trained on the use of the RTOP in an attempt to give them an intimate understanding of the elements of reformed teaching and were an integral part of the training model EMIT. Control GTAs received a copy of the RTOP instrument during the pre-semester interview but were not trained in its use. Students in both the treatment and control sections were asked to assess their GTAs' performance during recitation by the use of the Student Survey instrument and observation 1, 7 and 14 were scored and compared.

RTOP

All GTAs were assessed initially and then periodically during the semester using the Reformed Teaching Observation Protocol (RTOP) for evaluation of their teaching. For the comparative treatment and control GTAs' RTOP scores with national means see Table 15. Assessed was the GTAs' adherence to the

EMIT Model (treatment group) compared against the traditional teaching model (control GTAs). See Appendix A for the RTOP instrument, itself.

The results can be seen in Figure 16 for the graduate teaching assistants in the treatment group and show that the treatment GTA s "A' and "B" had baseline and week fourteen RTOP scores of 51% and 87% and 50% and 82%. These scores reflect a change in teaching method as reflected by the RTOP scores over the semester of 37 percentage points and 32 percentage points, respectively. By comparison, the graduate teaching assistants in the control group, GTA "C" and GTA "D" had RTOP baseline and week 14 scores of 44 percentage points, 53% and 45%, 48% an improvement of 13 percentage points for GTA "C" and 3 percentage points for GTA "D."

Treatment GTAs' baseline RTOP data was gathered during the training week, prior to the fall semester as they taught mock lessons to each other and before they were trained on the RTOP instrument itself. Control GTAs baseline data was gathered during the first recitation observation. Comparing the normalized baseline RTOP scores of the treatment GTAs (50% and 51%) Vs control GTAs (44% and 45%) a 5 to 7 percentage point range can be seen. This may point out a difference in initial GTA receptivity to the reform method which is supported in some of the interview data between treatment and control GTAs examples of which can be seen in the Table on page 123.

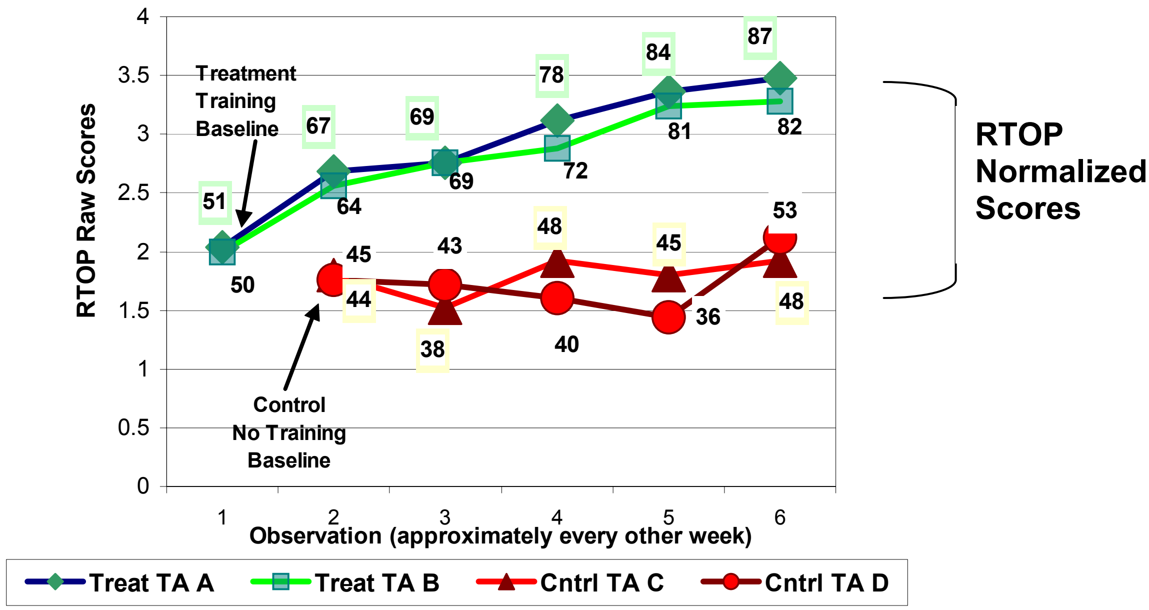


Figure 16 Reformed Teaching Observation Protocol Results: TA Treatment vs Control

In Table 15, National RTOP scores comparisons for physics instruction in various course types are shown. Instructors of traditional courses typically score lower than 45 percent on the RTOP, whether at the high school or university level.

Table 15 *Comparative RTOP Scores for Physics Course Types*

RTOP Scores Examples Type of Reformed Physics Course, Nationally*	Ave.Scores (%)
⇒ Traditional university lecture (passive)	< 20
⇒ University lecture with demonstrations (some student participation	< 30
⇒ Traditional high school physics lecture (with student questions)	< 45
⇒ Partial HS reform (some group work; most discourse still with teacher)	< 55
⇒ Medium sized (n > 50) university lectures with Mazur-like group- work (ConcepTests) and a student Personal Response System	55-75
⇒ Modeling curriculum (varies with amount and quality of discourse)	75-99

*(Piburn et al., 2000; MacIsaac & Falconer, 2002)

Student Survey of GTAs

The Student Survey questions had a one-to-one correspondence with questions on the RTOP, designed to reflect student perspectives on the adherence to the reformed teaching methods by their GTA, during recitation. Students were asked to respond to questions, recorded at week 1, 7 and 14. The Student Survey is available in its entirety in Appendix E.

In Table 16 the results of a reduced data set (due to missing data on the three measures used for the DFA criteria) can be seen to be mixed.

Table 16 *GTA Evaluation by Students: Results of the Student Survey*

GTA	Student Survey Scores (%) Week		
Treatment:	1	7	14
GTA "A"	74	61	89
GTA "B"	**62**	72	**75**
Control:			
GTA "C"	59	68	61
GTA "D"	**69**	71	**78**

Treatment GTA "B" and Control GTA "D" have similar scores and gains from Week 1 to Week 14

As shown in Figure 17 treatment GTA "A's" students reported a 15 percentage point increase in their GTA's adherence to methods of reformed teaching as assessed by the Student Survey. Students in treatment GTA "B's" recitation sections reported a 13 percentage points increase on the same measure. The control, GTA "C's" students reported a 2 percentage point increase, while the control GTA "D's" reported a 9 percentage point increase over the initial assessment in week 1.

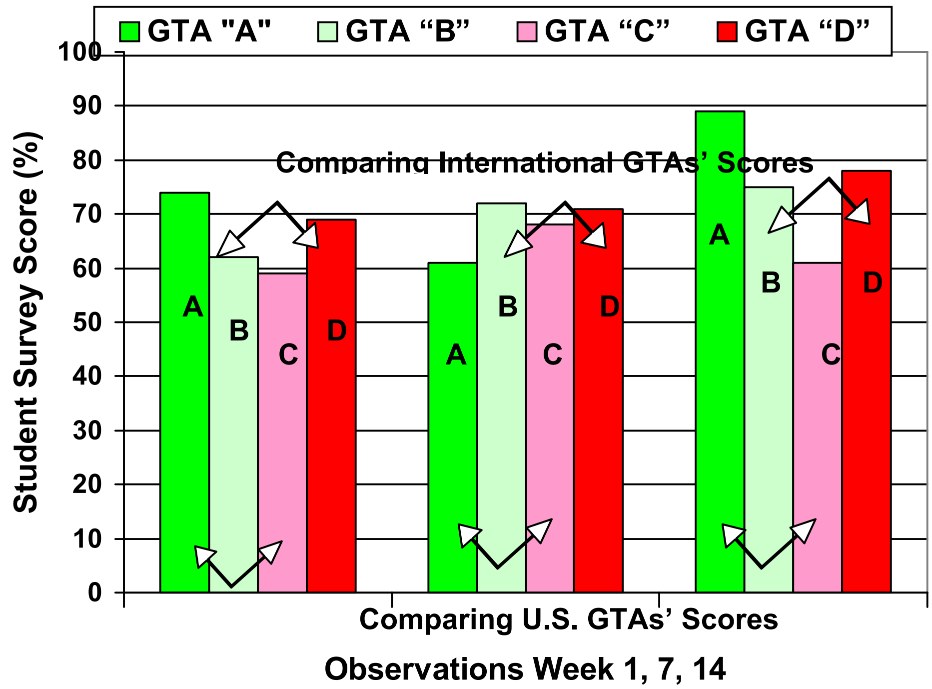


Figure 17 Graphs of the Results of the Student Surveys

Comparisons between student evaluations of the two international GTAs reveal similarities as can be seen in Figure 17. Qualitative data also show a cultural difference between the teaching these GTAs had experienced as students (traditional lecture) and the experiences of the GTAs from the U. S. Especially striking were the expectations of physics background these international GTAs assumed for their students. The two international GTAs' evaluations by students were similar. However, the two U.S. GTAs' scores were dissimilar. The dip in the control GTA “A’s” assessment scores seemed to be due to occurrences of student frustration at mid-semester at a professor’s change of format on tests, as reported in student and GTA interviews. GTA “C” had a rise and then a dip in student satisfaction on the Student Survey. The student comments on the survey suggest that this GTA had difficulty communicating and articulating basic physics concepts to students during recitation.

Qualitative Results

Student Survey Comments

Students recorded comments on the Student Survey instrument, during each evaluation reflecting the style of teaching of their GTA as well as logistics about the context of the lesson at hand. These comments were recorded on the Student Survey instrument. The comments represented below show typical and prevalent examples of differences between treatment and control students for observations 1, 7 and 14 on the Student Survey.

Example One: Student 1 in the treatment GTA “A’s” section, during observation 1, expressed that he felt encouraged to explore novel applications of the concepts learned in the homework. By observation 14, he expressed that he is encouraged to solve many types of problems and use alternative strategies that involve examples that are real world such as in car crashes. This student shows enthusiasm for the atmosphere created in the recitation section by the treatment GTA. This student, although challenged was interested and involved in the learning process.

Example Two: Student 1 in the control GTA “C’s” section in observation 1 said that she had followed instructions and did not reflect on what she understood. By Observation 14, she is frustrated that the GTA cannot seem to explain in terms she can understand, the fundamental concepts she is supposed to learn. This student is confused by this GTA’s traditional style and voices a need for her GTA to be more accessible and sensitive to student needs.

Other quantitative evidence used to assess the adherence to the instructional model, also provided results for research question 3, where students’ conceptual understanding was measured. Evidence for research question one is supported by the Discriminant Function Analysis results which, in turn support research question 3. So, rather than repeat these measures, they will be discussed, later in this chapter, under research question 3’s results.

Research Question 2

What is the effect of the EMIT model on the graduate teaching assistants’ understanding of the nature of physics and physics teaching?

Quantitative Results

Quantitative measures that provided evidence for the GTA adherence to their beliefs about the nature of physics and physics teaching were: 1) the MPEX2, Part I, 2) the pre-post interview data and 3) the RTOP observation comments and scores.

MPEX2, Part I

The Maryland Physics Expectations Survey, iteration 2 was designed to measure epistemological beliefs of physics students and instructors, using clustering of coherence and concept items. Evidence of GTA change in their beliefs was derived quantitatively from the first twenty-five items on the survey (Part I) and about physics teaching on the last 11 items, (Part II). Since Part II of the MPEX asked for qualitative responses, these data were included in the qualitative analysis section that follows. Item clusters that address reformed teaching were designated by the authors of the MPEX as items 9, 17 and 19 which are examined in more detail, later in this chapter.

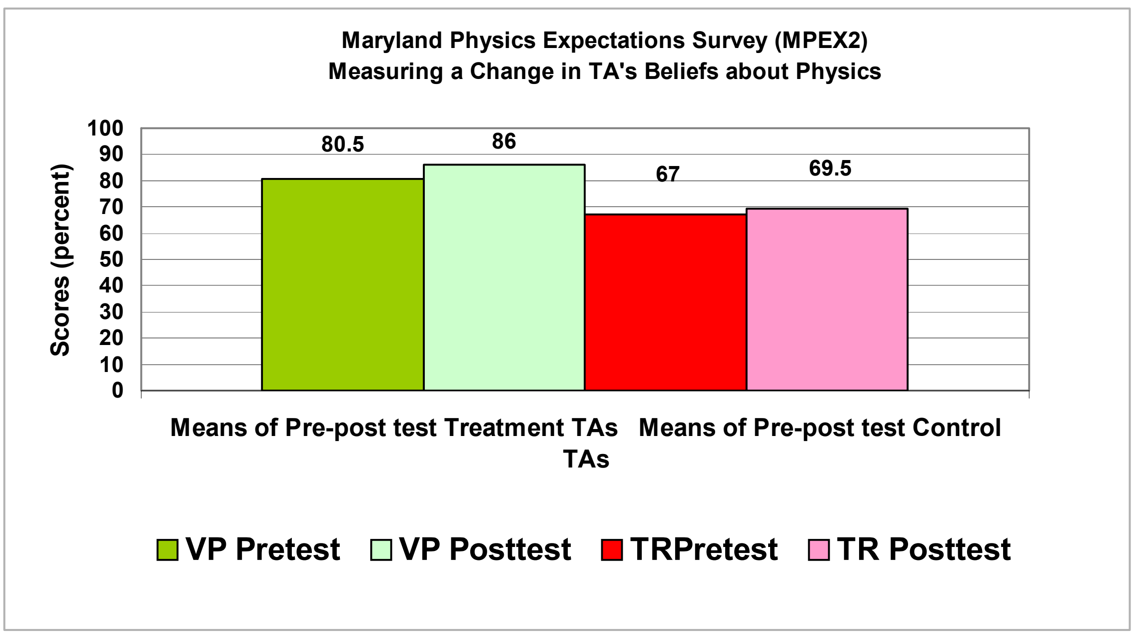


Figure 18 GTA Beliefs about the Nature of Physics: MPEX2, Part I

On the MPEX2, Part I, the treatment GTAs' beliefs, although starting at a higher point (much like their RTOP scores) matured at a greater rate, according to items measuring coherence (connectedness) from the pre to the posttest. This difference can be seen in Figure 18. Reality items measured connections between physics and the real world and were also included in the Part I scores pre and post semester. See score comparisons in Table 17.

Although beliefs about the nature of science are generally very tenacious to change according to Lederman (1999) and others, there is a marked difference in the mean change in the scores of the treatment GTAs compared with the control group on the items measured as can be seen in Table 17.

Table 17 *GTA Beliefs about the Nature of Physics and Physics Teaching, Part I*

MPEX 2, Part I Scores (%)					
Treatment (VP) Means		**Control (TR) Means**		**Change in Number of Percentage Points**	
Pre/Post		Post		Treatment	Control
80.5	86	67	69.5	5.5	2

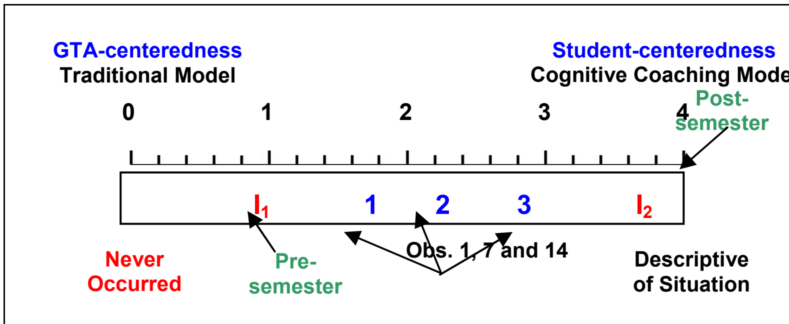
In Figures 19 a – 19 b, the graphs display each treatment graduate teaching assistant's adherence to the Cognitive Coaching model, as assessed by video observation samples taken at observations 1, 7 and 14. These video data were assessed further for inter-rater reliability on the instrument by a second local researcher (r = 0.95) and by two external researchers, one of whom was one of the original authors of the instrument. The external correlation coefficient for these data was r = 0.99. The graphical display was constructed by coding items 1, 15, 19 and 22 of the RTOP for GTA beliefs about the nature of physics and physics teaching.

These results for the control group graduate teaching assistants contrast these views compared to the treatment GTAs. The scale parallels that of the RTOP with a score of 0 for GTA-centeredness (traditional teaching) at the left end and a score of 4 meaning not only beliefs but also teaching performance that reflect student-centeredness (reformed teaching) on the right end of the scale. Also added to this display were the pre and post interview data, coded on these same items.

Qualitative Results

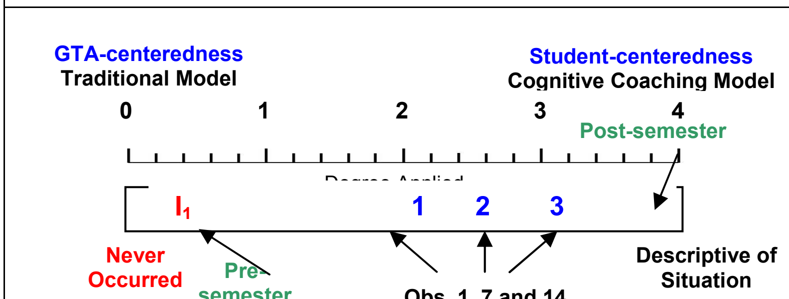
MPEX2, Part II

In part II of the MPEX2 instrument, the graduate teaching assistants were asked to choose how they would respond to various teaching scenarios. They were then asked to further comment on their selections. In Figure 20, it can be seen that on this part of the survey instrument, treatment GTAs matured in their understanding of the Nature of Physics compared to the control GTAs.



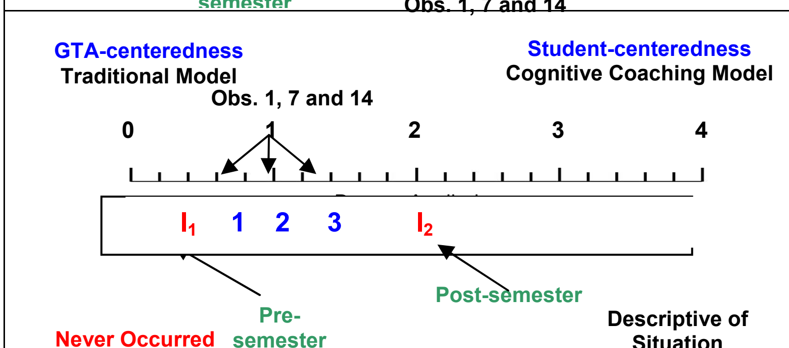
TA "A"

Interviews and Video Observations were tabulated and graphed for Video observations 1, 7 and 14.
Increases from 1 to 3.75 were observed over the semester for GTA "A" of the treatment group. This GTA had the second greatest gain.



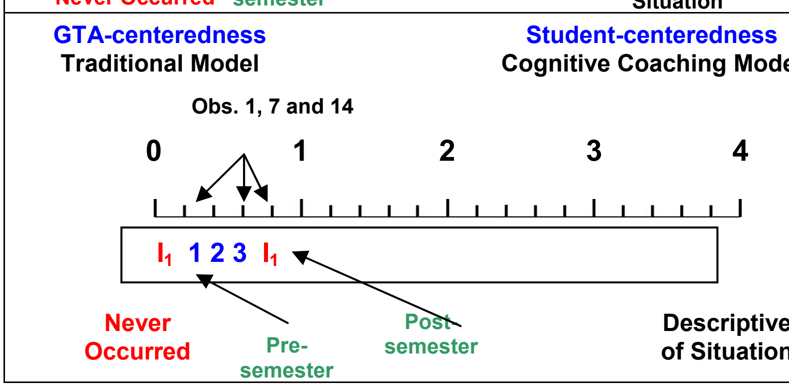
TA "B"

Interviews and Video Observations were tabulated and graphed for observations 1, 7 and 14 as well as for pre and post semester data. Increases from 0.1 to 3.75 were observed over the semester for GTA "B" of the treatment group. This GTA had the greatest gain.



TA "C"

Interviews and Video Observations were tabulated and graphed for observations 1, 7 and 14 as well as for pre and post semester data.
Increases from 0.2 to 2.0 were observed over the semester for GTA "B" of the treatment group. This GTA had the second least gain.



TA "D"

Interviews and Video Observations were tabulated and graphed for observations 1, 7 and 14 as well as for pre and post semester data.
Increases from 0.2 to 1.0 were observed over the semester for GTA "B" of the treatment group. This GTA had the least gain.

Figure 19 GTA Beliefs about the Nature of Physics and Physics Teaching and Adherence to EMIT as Demonstrated through RTOP and Interviews

Table 18 and Figure 20 show almost no difference in the change in understanding about the teaching of physics between treatment and control

GTAs. Changing views about the Nature of Science and science teaching require explicit instruction in the subject addressed in order to effect that change (Lederman, 1999).

Table 18 *GTA Beliefs About the Nature of Physics and Physics Teaching, Part II*

MPEX 2, Part II. Scores (%)					
Treatment (VP) Means		**Control (TR) Means**		**% Change**	
Pre/Post		Pre/Post		Treatment	Control
64.8	68.8	53.6	57.6	6.2	7.5

Comments by treatment and control GTAs on the pre and post MPEX2 assessments are given in Table 19. The full MPEX2 instrument is found in Appendix F. On the MPEX2, Part II, the graduate teaching assistants made comments on items that assessed their attitudes toward the nature of physics teaching. These items, correlated with the results on the MPEX2, part I, coded for coherence and reality support the contention that treatment GTAs may have

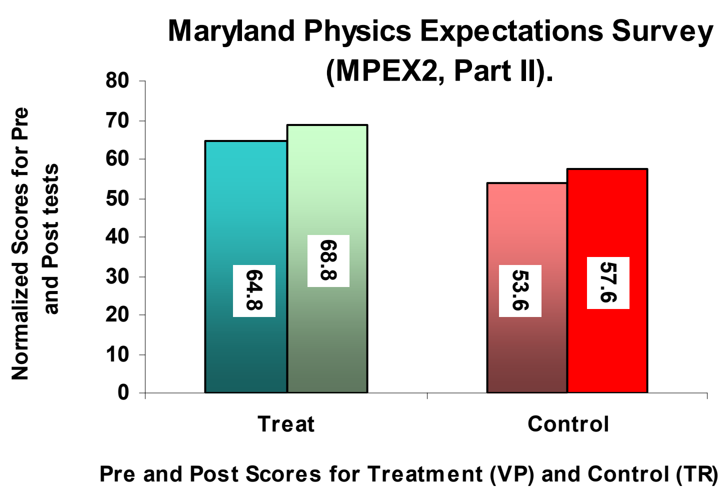


Figure 20 GTA Expectations about the Nature of Physics MPEX2, Part II

begun the study at a more mature level of understanding about the nature of physics, but their understanding of the nature of physics teaching, itself did not undergo significant change by the MPEX2, Part II comments highlighted in Table 19 show that treatment GTAs thought more about teaching design and environment and about how to improve instruction for students. Disaggregating the data for each GTA reveals mixed results for GTA A and C, consistent with the Student Survey results previously examined.

A specific example is illustrated by the GTAs' responses to MPEX2 item 32 below.

Table 19 *GTA Sample Comments on the Pre and Post MPEX2 Assessments*

GTA	Group	GTA Comments **MPEX Item #32** Many students report that they sometimes come away from a lecture felling like they understand a given topic or concept; but when they try to complete a homework problem on that topic, they get stuck. Why do you think this happens?	
		Pre	**Post**
GTA "A"	**Treatment (VP)**	"It takes more than an isolated example to truly understand a topic"	"An understanding of a concept requires different skills from solving a problem. You need a vision of the whole system and breaking down into parts."
GTA "B"		"Must understand to really solve a problem correctly."	"Lecture doesn't always give a deep understanding or knowledge how to apply the concept.
GTA "C"	**Control (TR)**	"Thinking will give students more understanding, after the lecture."	"Most students rely on lecture only to get the information and don't practice problems or think."
GTA "D"		"(Students) must do background work as well as come to lecture."	"You must have some techniques before you can solve problems.

GTA Concerns and Comments

Only the treatment graduate teaching assistants received initial instruction and subsequent instruction occurring weekly throughout the Fall Semester. The control graduate teaching assistants received no instruction, but were assessed and observed similarly to the treatment graduate teaching assistants, throughout the semester. The concerns and comments of the graduate teaching assistants were captured each day of the pre-semester instruction and periodically during the semester. These data were in the form of structured and unstructured interviews, formal and informal feedback at meetings and during videotaped observations of the recitation at observations times 1, 7 and 14.

Although all graduate teaching assistants expressed some concerns about their teaching role, the treatment GTAs' expressed more satisfaction with their teaching as they gained experience with the EMIT model and reform teaching skills were acquired. Control GTAs expressed more concerns, more often and expressed doubts about their teaching ability throughout the semester. Example comments by both treatment and control GTAs are given in Table 20.

Diagnoser and Interview Data

The use of Diagnoser (Hunt & Minstrell, 1994) was an attempt to reveal GTA understanding of basic physics concepts and the problem solving process in physics. Both treatment and control GTAs were given a password and login and urged to perform the operations indicated online. Treatment GTAs performed these assignments during the instructional week prior to the Fall Semester 2003 and the control GTAs after the Semester began.

The results of GTAs' perceptions about basic force and motion concepts and the process of problem solving are also seen against their experiences in learning physics and how they view their role as instructor.

In comments gathered during the pre and post interviews, GTAs in both treatment and control groups reflect on how they view the nature of physics and how to teach physics, their conceptions about teaching physics students and how they would adhere to or change the way they had been taught physics as undergraduate students. These comments are summarized in Table 21.

GTAs expressed some frustration in the post-interview about some difficulty in identifying correct physics concepts not only in the Diagnoser inventory questions, but during instruction; GTAs critiqued the FCI questions as Well. Their initial comments, in general, indicated that the question under scrutiny must be a "trick question."

Despite the GTAs critical assessment of some of the FCI and Diagnoser items, they agreed that conceptual understanding is sometimes difficult to achieve but is an important aspect of fundamental physics understanding that is rarely explicitly taught. Graduate teaching assistants' attitudes about teaching, problem solving and about their role in the articulation of the physics course is also important to reveal. The context, in which the expert is embedded can impact the complexion of the lesson and ultimately student (novice) understanding of physics concepts and problems.

The Importance of Confronting GTA Prior Learning

Misconceptions are grounded in students' prior learning in classrooms and from interaction with the physical and social world. Researchers have agreed that students' misconceptions about force and motion are the result of the assumptions they make and the models they build as they observe and interact with the physical world.

To neutralize the interference of misconceptions, instruction should confront students with the disparity between their misconceptions and expert concepts. When the disparity becomes explicit, students will appreciate the advantages of the expert concepts and give up their misconceptions (Smith et al., 1993).

Table 20 *Example GTA Concerns and Comments about Physics Teaching*

GTA Answers to questions posed at Observation Question Posed: **"How do you conduct appropriate questioning?"**				
Observation	**GTA "A" (Treatment)**	**GTA "B"**	**GTA "C" (Control)**	**GTA "D"**
1	"Students don't respond, when I pause for them to ask questions. I have to drag it out of them."	"I don't know when enough time to wait is."	"I don't know how to keep students from talking at the same time?"	"Students don't come to class prepared and they don't seem to care."
7	"We need more time to answer student questions. The students need more time to do the context-rich problem."	"Students need to ask more questions, during the problem solving. I can't know when they have trouble."	"Students don't seem to be able to follow the math. I think that they are not doing the homework."	"They (students) don't come to class. They don't even know what the homework is or ask any questions."
14	"When I try to write these recitation problems, I can see how they are different from the homework problems. The students aren't held responsible for these on their exams."	"There isn't enough time to review and to do the (CPQ) problems. I need to use some of the lab time, mostly. The students want to have enough time."	"Students pay more attention when they have a test or just took a test."	"I don't see how these students can do well when they expect us to do it for them. Their skills are not very good, coming into this class."

Although none of the GTAs' Diagnoser data were comprehensive, the concepts that were expressed by the GTAs do indicate variation in their conceptual grasp of some fundamental physics concepts – some alternate conceptions existing side-by-side with a high level of expertise in physics content and problem solving abilities. See Table 22 for examples.

Table 21 *Pre and Post Interviews on the Nature of Physics Problem Solving**

TA	*roup*	GTA Interviews	
		Pre-interview	**Post-interview**
GTA "A"	**Treatment (VP)**	Main reason for teaching physics was the impact of her physics teacher who was excited and infused physics with that excitement. Tried to model this in tutoring. Cares about teaching effectively, showing examples in as many ways as needed to help students succeed and understand the concepts.	This type of teaching is more challenging because students ask a lot of good questions And care whether they understand. Time management is a challenge. It helps when everyone feels that they are all on the same team. The rules and expectations need to be clear from the beginning. More time is needed to recap. Students mostly lost the fear of asking, when they needed help.
GTA "B"		Only experienced traditional teaching and learning – lecture method. These methods were not always easy way to learn. Explaining what happens is in our nature math can help. Important to get the physical concepts and an exact definition.	I am impressed with students' desire to share ideas. Each person should be held responsible for his or her success. Not enough time to do all that we could. We all learned a lot about interaction – used to be material-focused and now are student-focused. Need to be able to quickly evaluate student level. This is the first time that everyone knew student names. There exists a gap between the ideal and what can be accomplished. There has been too much focus, in the past on how to do "it" and not on "what it means." All parts of the course need to compliment each other.
GTA "C"	**Control (TR)**	Didn't have a good teaching model. Went to many schools. Always felt math was intuitive. Didn't know about teaching but needed money. Wanted to try it and to do a good job and learn how to do it well. Wants to emphasize problem solving.	It was good learning from the students so that I could begin to see what they needed. I liked the communication so that I could figure out how to answer their questions. Sometimes the students were hard to control. I would like to learn more about how to teach more effectively and more clearly communicate with students.
GTA "D"		Always good at math and wanted to have an application of math. Only has seen traditional methods of problem solving some of his teachers weren't very good. Wanted some teaching experience. Precision is important. Mistakes must be eliminated.	Teaching seemed to get a little easier, as the semester went along. Recitation quizzes were motivational. Half of students still had poor attitudes and were not prepared. It is important to understand, but students do not take the time – they just memorized and didn't think. Some students didn't read their book.

*Semi-structured interview techniques (Lincoln, 2003, personal communication)

Even as graduate teaching assistants assume the role of experts as they cognitively coach student novices, they must be made aware of how they may hold misconceptions themselves that could impede their success as they convey their ideas to students. If prior conceptions are made explicit, discussed and addressed, GTAs become aware of how important acknowledging and addressing student's naïve conceptions are.

Table 22 *Sample of GTAs Naïve Conceptions of Force and Motion as Revealed in Diagnoser**

	Treatment GTAs (VP)		**Control GTAs (TR)**	
Concept	**GTA "A"**	**GTA "B"**	**GTA "D"**	**GTA "C"**
Making Sense of Graphs	Some confusion about equality of intervals on axes		Some confusion about equal scaling on axes	Some problems referencing the axes and data
Relationships and Equations		If an object moves, the interaction forces must be unbalanced.	Interpretation unrealistic to real world	Some problems explaining relationships/scaling
Slope				Problems with unit interpretation

*(Hunt & Minstrell, 1994).

Research Question 3

What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Quantitative Results

Quantitative evidence that supports the treatment group GTAs' impact on student conceptual understanding and problem solving improvement is given by the data gathered on the following instruments/tests: 1) Discriminant Function Analysis (DFA) test whose criterion variables are the student FCI results, Student Survey scores and Final Course Grades; 2) the FCI pre/post results for all groups, treatment and control; and 3) two measures of effect size for the FCI data, Cohen’s d and Hake’s <g>. Results were examined closely qualitatively for individual differences between GTAs as well as between groups.

Discriminant Function Analysis (DFA)

Discriminant Function Analysis (DFA) is a multivariate statistical method used to determine which variables discriminate between two or more naturally occurring groups. DFA is similar to multiple regression and is also known as Fisher Linear Discriminant Analysis (Kachigan, 1991). In this study, student scores provided the criteria for the DFA data for each TA. A 4-way DFA was then run in SPSS. The only criterion variables that could be used were those on which there were student scores: 1) the FCI, 2) the Student Survey and 3) Final Course Grades, precluding the use of some of the other quantitative data, such as the MPEX and RTOP.

Those instruments measured GTA adherence to reformed teaching methods against national norms. As can be seen in Figure 21, group Centroids are completely independent (do not overlap) for each GTA (group). This gives a visual picture of the independence of the groups chosen for examination in this study. In Figure 22, all study GTA students’ FCI pretests and posttests are plotted, showing the degree to which the pretest predicts the posttest scores.

But, because of the need to reduce the data from this set to exclude missing data on the three criterion variables the use of the entire data set is precluded.

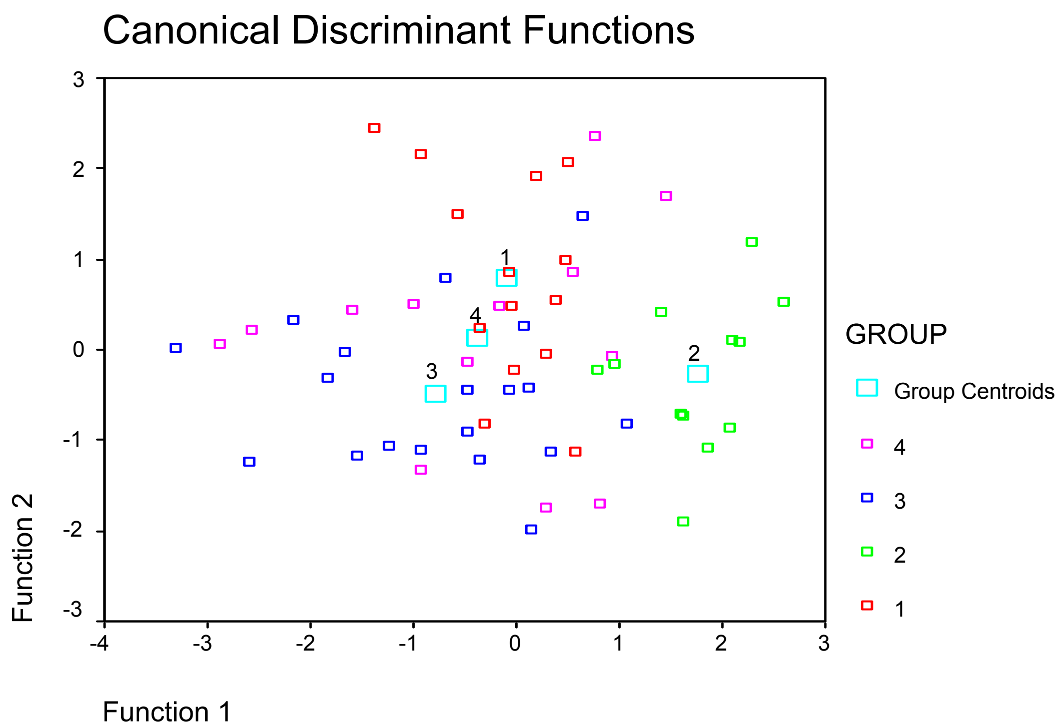


Figure 21 Independence of Centroids

Several assumptions needed to be met for the data to qualify for a DFA analysis: 1) the data had to represent a sample that was multivariate normally distributed; 2) the homogeneity of variance test was met as is evident in the standard deviation data shown in Table 23; 3) the means for variables across groups are uncorrelated with the variances and 4) variables that are used to discriminate between groups are not completely redundant (Grimm & Yarnold, 2003).

Condition four was met in that the criterion variables were independent student scores that were not derived directly from each other. And, in this study, the predictions were done, *post hoc*, after the study data were acquired. In Figure 21 a display of each of the Centroids also can be seen showing a non-linear dependence of each of the criterion variables. These Centroids were distinct for each TA's group: 1, 2, 3, and 4 (corresponds to A, B, C, and D at the top of Table 24).

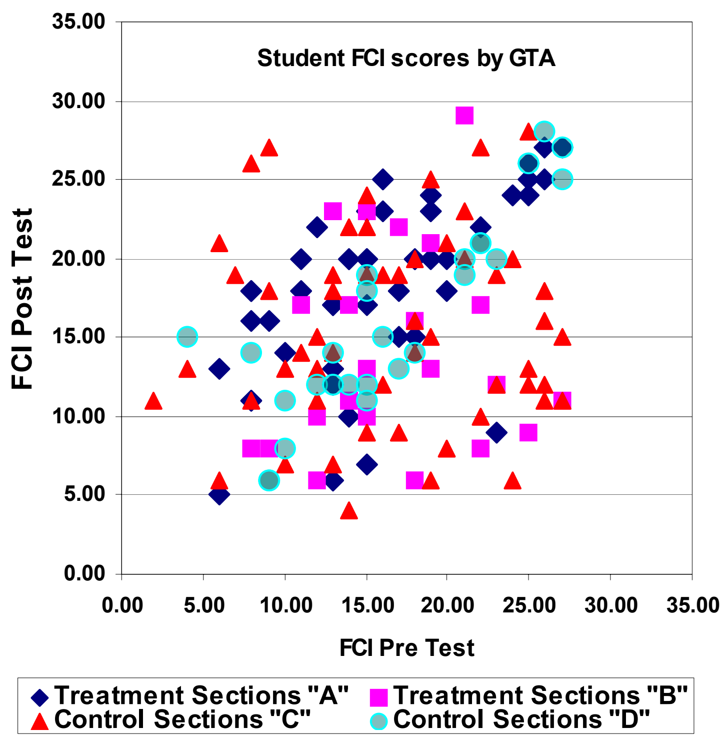


Figure 22 Scattergram of FCI Pre vs Post for ASII GTAs' Sections

A two-group case was run first for the data for both treatment and control groups for the descriptive statistics see Table 23. The variables with the largest (standardized) regression coefficients are the ones that contributed most to the prediction of group membership as can be seen in Figure 23 (Grimm & Yarnold, 2003). The greatest change in the FCI occurred in the treatment group (18%) while the change in the control group's student FCI scores was (9%).

Table 23 *Treatment/Control Group 2-Level DFA Descriptive Data*

GROUP	Measure	% Mean	Std. Deviation	Valid N (listwise)
				Unweighted
VP	DELTAFCI	**10.08**	13.55	26
	SS	8.83	12.66	26
	FINALGR	81.42	14.03	26
Control	DELTAFCI	**4.63**	15.76	32
	SS	-0.61	15.11	32
	FINALGR	65.03	18.63	32
Total	DELTAFCI	**7.07**	14.93	58
	SS	3.62	14.73	58
	FINALGR	72.38	18.51	58

In this study, the four-group Discriminant Analysis revealed more fine-grained information and so was preferred. The three variables selected (Final Student Survey scores, Final FCI scores and final grades) were the only variables available to the researcher that had scores from student tests. The DFA was then run (in SPSS) showing that the first function yields the most overall discrimination between groups.

As shown in Table 24, the four-way DFA is displayed with the GTAs defining the groups and the student scores on the 3 measures defining the criterion variables. Looking at each GTA individually and each FCI score individually, revealed that there were low performing GTAs as well as higher performing GTAs in each group. This was especially true when students with missing data were removed. The combination of criteria, however, gives a more meaningful overall picture of the differences between the treatment and control groups. The 2-level DFA was initially run in anticipation of a highlighting of group differences between treatment and control student scores. This hypothesis was borne out in the data. It was found, however, after a 4-level test (one on each GTA in this study) was run, that the differences lay more with the individual GTA rather than in the groups. In other words, in the treatment and control groups, although performing differently as a group on some measures performed similarly on others.

Table 24 *4-Level DFA Descriptive Data*

	Tool	Means	Std. Deviation	Valid N (listwise)
GROUP				Unweighted
Treatment				
A	**FINALFCI**	63	20.445	14
	FINALSS	81	13.023	14
	FINALGR	70	7.610	14
B	**FINALFCI**	53	16.706	12
	FINALSS	70	15.315	12
	FINALGR	95	3.785	12
Control				
C	**FINALFCI**	53	21.019	19
	FINALSS	63	12.977	19
	FINALGR	61	17.576	19
D	**FINALFCI**	73	16.510	13
	FINALSS	65	16.838	13
	FINALGR	71	18.866	13
Means	**FINALFCI**	60	20.415	58
	FINALSS	70	15.720	58
	FINALGR	72	18.511	58

Eigenvalues associated with discriminant functions showed how well these functions differentiated between the groups. (The Eigenvalue for a discriminant function is the ratio of the between-groups sums of squares to the within-groups sums of squares for an ANOVA, with the discriminant function as the dependent variable and the groups as levels of a factor). The only Eigenvalues from the real data, which are significant, are those that are significantly larger than the corresponding random-data Eigenvalues.

In this study, the first discriminant function accounts for 68.4 percent of the variability of the scores among the three criterion variables. The higher the Eigenvalue, the more variance is accounted for, indicating the combination of criterion variables that make up the first function (FCI, Student Survey and Final Course Grades), taken in combination, are good indicators of differences between individual GTAs. See Table 25 for a display and comparison of these data. Eigenvalues are another measure of the size of the effect for multivariate tests.

Table 25 *Eigenvalues for Each Function*

Function*	Eigenvalue	% Of Variance	Cumulative %	Canonical Correlation
1	.936	68.4	68.4	.695
2	.265	19.4	87.8	.458
3	.167	12.2	100.0	.379

*First 3 canonical discriminant functions were used in the analysis.

Table 26 gives the Wilk's Lambda values for each of the functions, expressing the proportion of unexplained variance in the dependent (criterion) values (FCI, Student Survey and Final Course Grades). The Wilk's Lambda data, along with the Chi-squared values, show that statistical significance is attained for these data. It remains to be seen (on tests of effect size) if this result actually translates into any practical significance.

Table 26 *Function Tests*

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 3	.350	56.2	9	.000
2 through 3	.677	20.1	4	.000
3	.857	8.3	1	.004

The Chi-square values assess whether there are significant differences among groups across the predictor variables. When checking the data for classification results – predictions of group membership given the data on three criteria – the following results are shown in Table 27.

Cross validation was performed in order to see if the predictor variables not only predicted group membership in this study, but would in future studies, if using the same criteria. In looking at the cross validation of beta weights, each case is classified by the functions derived from all cases other than that case. 65.5% of original grouped cases correctly classified. These data show that 60.3% of cross-validated grouped cases were correctly classified.

GTA's A, B, C and D made up the groups and the top half of Table 27 shows, how well the classification function predicts group membership in the sample. GTA "A" had 57 percent correctly predicted; GTA "B" had 91.7 percent correctly predicted; GTA "C" had 68.4 correctly predicted and GTA "D" had 46.2 percent correctly identified.

Table 27 *Classification Results Predicted Group Membership*

		GROUP	A	B	C	D	
Original	Count	1.00	8	0	3	3	14
		2.00	0	11	0	1	12
		3.00	2	1	13	3	19
		4.00	3	1	3	6	13
	%	1.00	57.1	.0	21.4	21.4	100.0
		2.00	.0	91.7	.0	8.3	100.0
		3.00	10.5	5.3	68.4	15.8	100.0
		4.00	23.1	7.7	23.1	46.2	100.0
Cross-Validated		1.00	8	0	3	3	14
		2.00	0	10	0	2	12
		3.00	2	1	12	4	19
		4.00	2	2	4	5	13
	%	1.00	57.1	.0	21.4	21.4	100.0
		2.00	.0	83.3	.(	16.7	100.0
		3.00	10.5	5.3	63.2	21.1	100.0
		4.00	15.4	15.4	30.8	38.5	100.0

In the bottom half of Table 27, labeled cross-validated, classification is predicted for the left-out cases. This should allow a prediction of how well new cases would be predicted (Grimm & Yarnold, 2003).

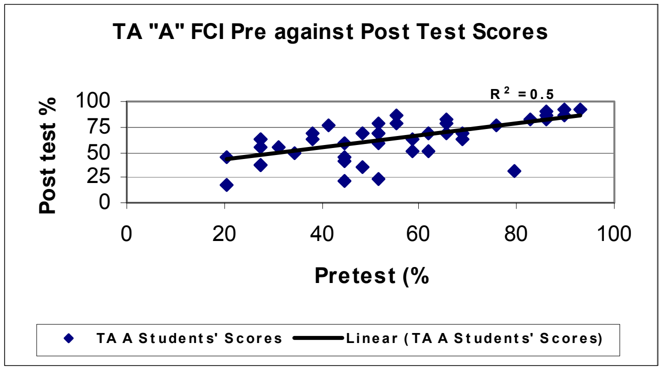
Measure of Student Conceptual Understanding: The FCI

The Force Concept Inventory is a 29-item multiple choice test whose impact derives from four factors:

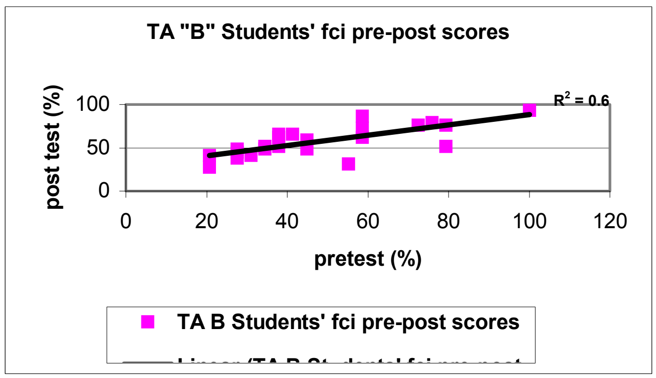
1) Widespread agreement within the physics community about the content
2) Test items appearing deceptively simple, leading most instructors to greatly overestimate the likely success rate of their students
3) Results reflecting rigorous and highly consistent validity and reliability tests across a large nationwide and many study constituency
4) Students' responses remaining resistant to any aspect of traditional instruction (Adams & Slater, 2002).

In Figure 23 (A-D) the FCI pre and posttest scores are plotted against one another for each GTA's recitation sections. Treatment group graphs are labeled A and B and control group graphs are labeled C and D. These data show R-squared correlation values for GTA "A" and GTA "B" to be 0.5 and 0.6, respectively. For the control GTAs "C" and "D," r-squared values are 0.6 and 0.7. These data show a significant linear correlation between FCI pre and posttest scores. The homogeneity-of-groups criteria are established through these data and student background data, gathered at the beginning of the semester for all GTA sections.

A



B



C

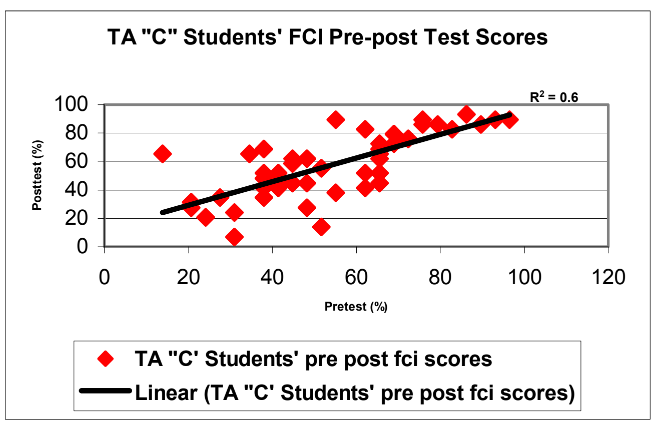


*Figure 23.*Treatment and Control GTAs' Student FCI Results

D

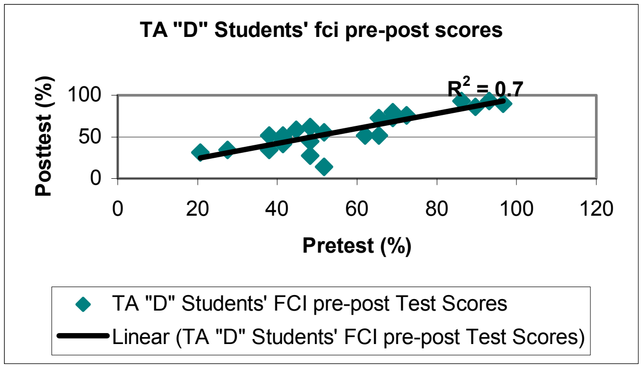


Figure 23. Continued

Effect Size Compared to National Data

In this study, two tests of effect size were performed in order to show the “practical significance” of these data. Results of these tests can be seen in Figures 24 and 25.

Cohen's d

Cohen's *d* is commonly used to calculate effect size. Cohen's d is a "standardized" measure found by dividing the difference in the group mean scores by the standard deviation (adjusted for sample size differences known as the "pooled" estimate of the standard deviation). Whereas "statistical significance" is based on a specific probability ["p-value"], it can be affected much more by sample size than effect size's interpretation.

Table 28 *FCI Effect Size Calculations for This Study*

Cohen's d = $M1$ - $M2$ / sd_{pooled}
(where sd_{pooled}= σ [(sd 1²+ sd 2²) / 2])
Cohen's d $_{Treatment}$ = 0.408 (modest effect)*   **Cohen's d $_{Control}$ = 0.149 (negligible effect)**
*An effect size of 0.25 or greater is considered "educationally significant"(Tallmadge, 1972).

In educational research, an effect size of 0.25 or more is commonly considered as "educationally significant "(Talmadge, 1972). See Table 28. To calculate the value of Cohen's d, this study used the means and standard deviations of the FCI data for the two groups.

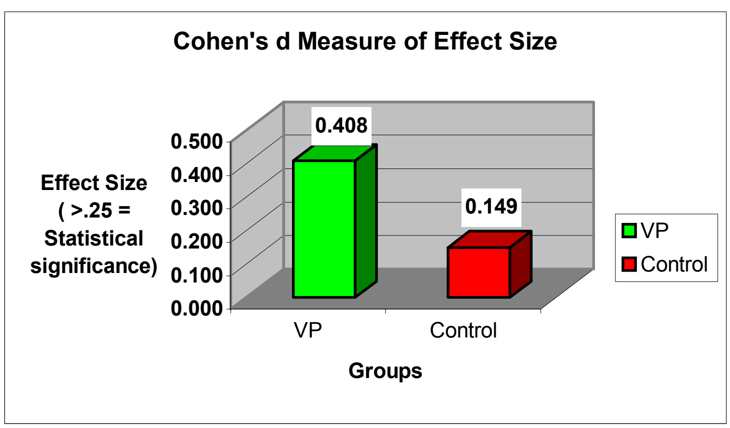


Figure 24 Cohen's d: A Measure of Practical Significance

The Hake Gain

The Hake gain (g) is an additional measure of effect size and practical significance. The Hake gain (*g)* measures the effectiveness of interactive engagement methods through scores on the FCI pre and posttest (Hake, 1998).

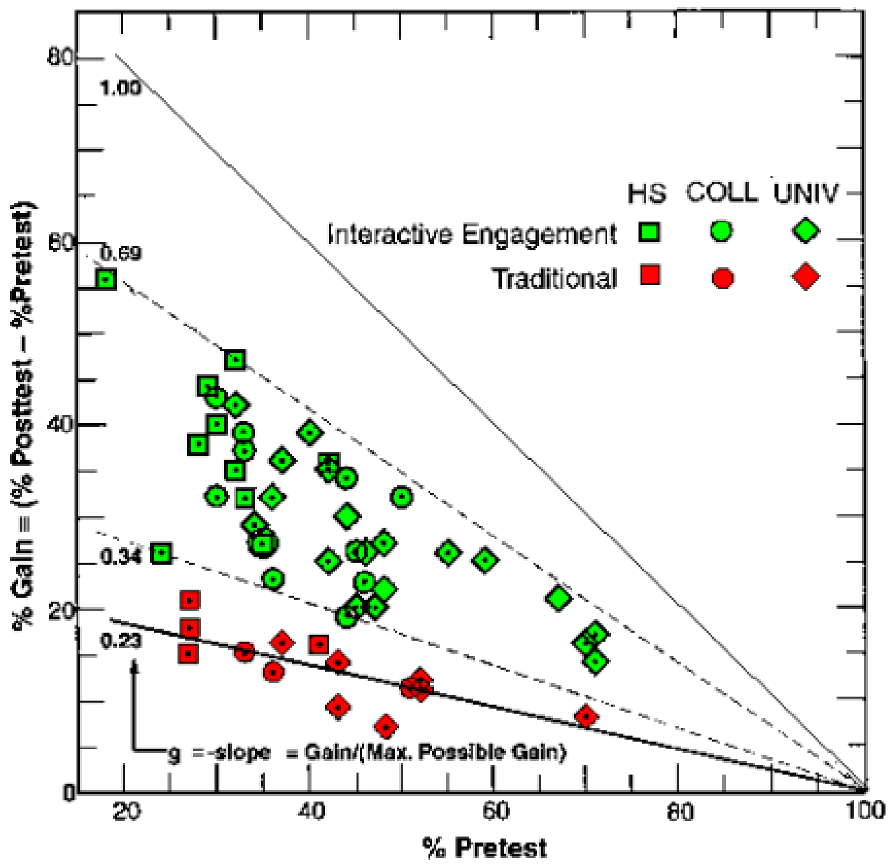


Figure 25 Hake Gain Compared to National Groups

Where $\mathbf{p_{pre}}$ is the pretest, $\mathbf{p_{post}}$ is the posttest, **G** is the mean difference and **g** is the Hake gain. The data is plotted on a graph of *%* Hake gain (g*)* VS % Maximum possible gain (from pre to posttest). A "*g"* > 0.2 is expected for “reformed” physics instruction. In Figure 25, the Hake Gain for our treatment (18%) and control groups (9%) is measured against national norms. Also included are comparisons between high school, college and university first physics courses both traditional and reformed.

Grade distributions for students in all treatment and control groups are shown in Figure 26. A marked upward shifting of the grades in the B, C, D and F categories was apparent in the treatment group. These data translate into gains on the order of 1/3 to 1/4 grade point gain for the treatment groups as compared not only with the control groups but with previous three years’ background data for this course. Numbers of students receiving a grade of ”A” were comparable across both groups. For a test of equivalency of groups, see the DFA and FCI Figures 21 and 23.

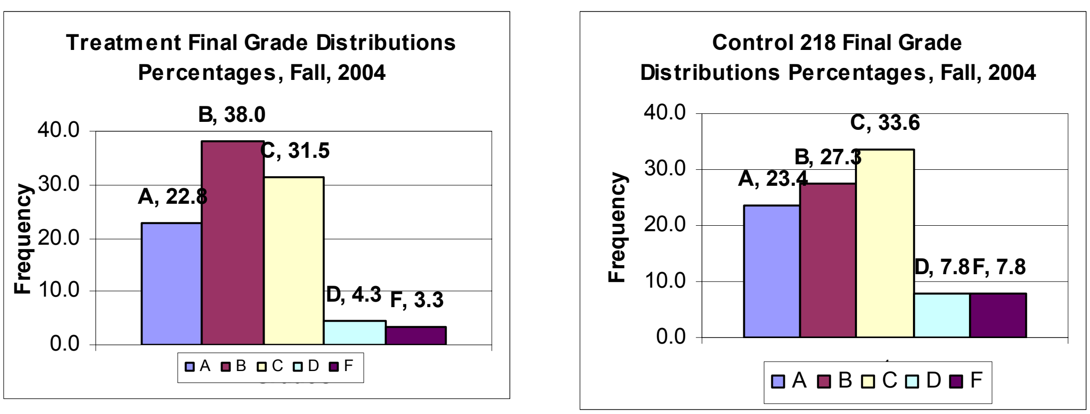


Figure 26 Overall Final Grades

Qualitative Results

Effective physics instruction encourages the kind of learning that leads to enhanced conceptual understanding; this occurs when solutions are constructed by the student and are guided by the graduate teaching assistant. Even if students can *recite* Newton's three laws of motion, responses to questions and their problem-solving performance usually reveal conceptions that are not in-line with their statement of the laws (Dykstra, Boyle & Monarch, 1992).

For research question 3, the qualitative evidence gathered included: 1) the student responses on the 5 FM2CA interactive simulations, 2) concept-rich problem scenarios, 3) video analysis of interaction patterns between students and transcripts of student comments during recitation.

Example Flash-mediated Simulation

Student conceptual understanding as they solved problems was assessed for both treatment and control groups by using the Flash-mediated Force and Motion Conceptual Assessment (FM2CA) online as a formative measure, during the semester. Students were directed by the GTAs to practice with the pre-assessments, learning the expectations and performance protocols, before attempting the subsequent three interactive simulations. Students interacted with each simulation, an example of which is found in Figure 27, and determined the answer to a multiple-choice question. The Flash Simulation shown asks students to determine the effects of weight and tension on a body oscillating in three different gravitational environments. Students could adjust tension, mass and select the planet on which this simulation occurred.

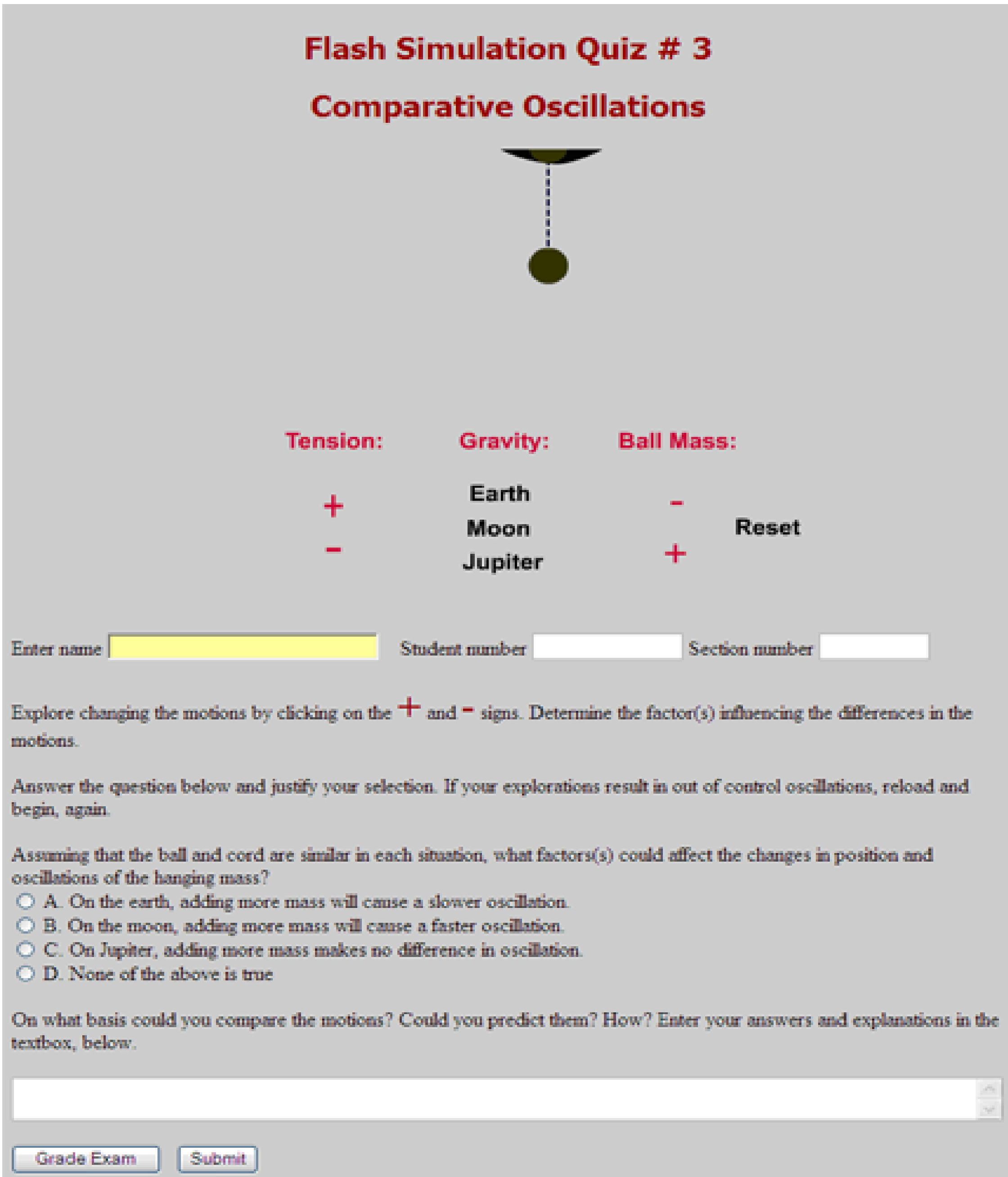


Figure 27 Interactive Simulations: FM2CA

Additionally, students were asked to justify the selection of their answers and to explain the rationale behind their reasoning. These data were captured and sample explanations are offered in Table 29. These simulation paralleled concepts learned in recitation, lab and homework, including interactions with the GTAs in the treatment groups.

All students interacted with the FM2CA on Comparative Oscillations. This was the final (5^{th}) simulation for students in both groups. For the treatment group, student **S1** correctly identified forces acting on the bob but made little explanation for the motion. Also in the treatment group, students **S2** and **S4** correctly identified the result of adding more mass (increasing weight with gravity present). And Student **S6**, in the treatment group offered a more mature approach through the suggestion of altering only one variable at a time. Student **S3** seemed to be confusing the effect of tension with increasing force.

In the control group, student **S1** did not fully explain however seemed to be on the right track with some of the concepts. Students **S2** and **S3** seemed not to be able to predict, based on the interaction. Control group student **S4** gets the motion backwards and doesn't fully explain the reasoning while student **S5** confuses the basic principle of mass with size. In the control group student **S6** had a well thought out, if incomplete procedure that only tested one variable overall.

On the basis of these data, more treatment students interacted with more correct explanations (5) than control students (1.5). This suggests that the interactivity with which the treatment GTAs taught impacted their students more positively than those methods used by the control GTAs.

Table 29 *Student Responses to Simulation 3: Comparative Oscillations*

Example Student Comments	**Treatment Group (VP)**		**Control Group (TR)**	
Scenario: Exploration and Prediction of the effects of differing conditions of g on an oscillating bob on a spring.				
Concept: Fundamental Relationship between Force and Motion	**S1:** Motions can be compared with respect to the force of gravity that's acting on the bob and also with respect to the force due to tension on the string.	**S4:** As seen in the simulation above, adding more mass on earth does cause the oscillation to occur more slowly. This is predictable because one would expect the greater mass to lower the time for each oscillation because the weight of the ball works against the tension in the string allowing for longer spaced oscillations.	**S1:** Less mass moves more easily and rapidly with the same tension.	**S4:** I think you could base the motions on the tension in the cord. The more tension you have in the cord the slower the oscillation, the less tension you in the cord the faster the oscillation.
	S2: Although the magnitude of the effect of gravity differs on each body, the effect is the same. Adding more mass on any planet will slow oscillation because the spring has to overcome a greater force in order to accelerate the ball upward.5	**S5:** As seen in the simulation, adding more mass on earth does cause the oscillation to occur more slowly. This is predictable because one would expect the greater mass to lower the time for each oscillation because the weight of the ball works against the tension in the string allowing for longer spaced oscillations.	**S2:** I compared the motions by watching them and seeing if one oscillated faster than the other. I wasn't very good at predicting	**S5:** The attraction due to gravity on the ball. I know the relative sizes of each
	S3: I could predict that higher tension would cause higher oscillations, higher gravity would cause faster oscillations, and adding more mass would slow the oscillations	**S6:** You can compare the motions by keeping everything constant in the system except for variables (such as tension). The motion could be predicted to some extent by knowing that Jupiter has the most gravity and the moon has the least. Also you can see that the higher the tension, the less gravity affects the ball. Higher mass results in a bigger change by gravity.	**S3:** I played with the little ball on the chain in the program and just tried each theory out until I found one that was true. Exam: Prototype 4	**S6:** As I added more mass to the ball around the Earth, the ball would move slower and opposite as I took away mass from the ball. The moon was the same as the Earth, as I added mass it appeared to have a slower oscillation. I don't think that I could predict them I just studied the reaction of each as I subtracted and added mass.

Example Problem-solving Scenario: Solving Concept-rich Problem*s*

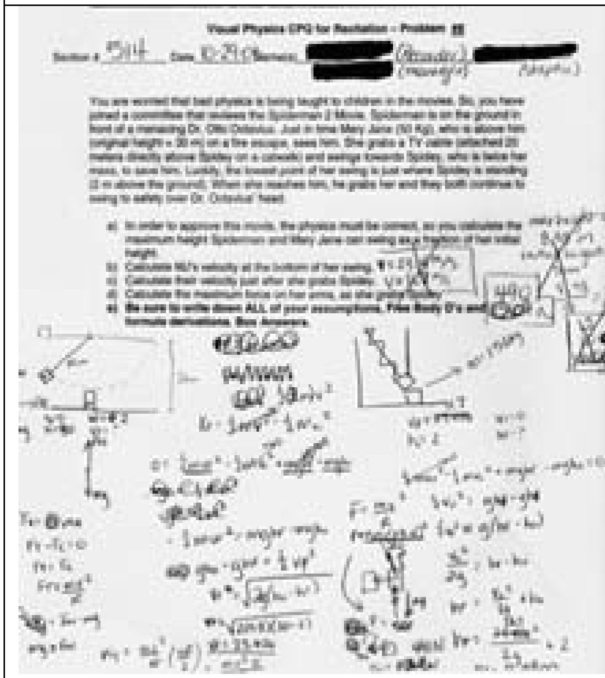
Analysis of video taken during the recitation, observations 1, 7 and 14, provided the problem-solving context for both the treatment and control groups. The room arrangement, example problem and model of the interactions during problem solving and solution model building are also provided in Figure 28 and 29. The example concept-rich problem was one solved only by the treatment group with an example of a typical traditional problem from the control group also shown. A "flow pattern" of typical interactions between GTA and students is also diagrammed in Figure 28 and 29, along with the differences in room arrangement. Students in the treatment group had pre-assigned roles during recitation (manager, skeptic and recorder) that culminated in cooperative group interactions between students and GTAs throughout the problem-solving process.

The Recitation Interactions

Video Analyses of student participation in the interactive-engagement problem-solving process were assessed at observations one, seven and fourteen. The criteria used to determine the degree of interactivity between the GTA-to-student and student-to-student interactively included RTOP items 11-20.

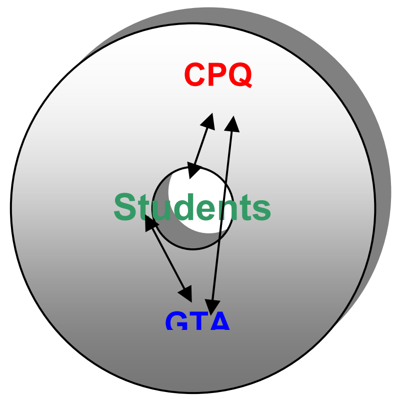
GTA-Student and Student-Student Interaction Dynamics During Solution Model Building

Treatment Group

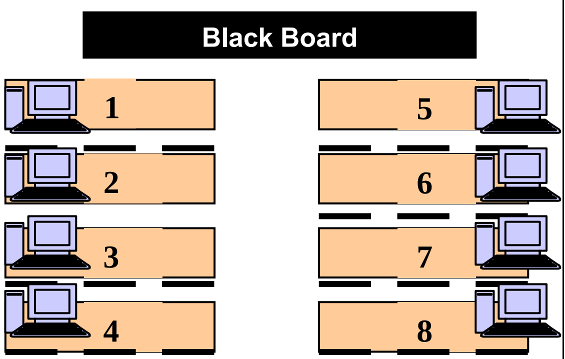


Interactions

GTA-Student



Physical Arrangement of Recitation/Lab Room



Interactions

Student-Student

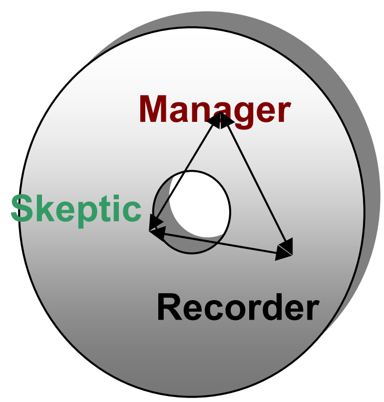


Figure 28 Treatment Group Concept-rich Problem #8

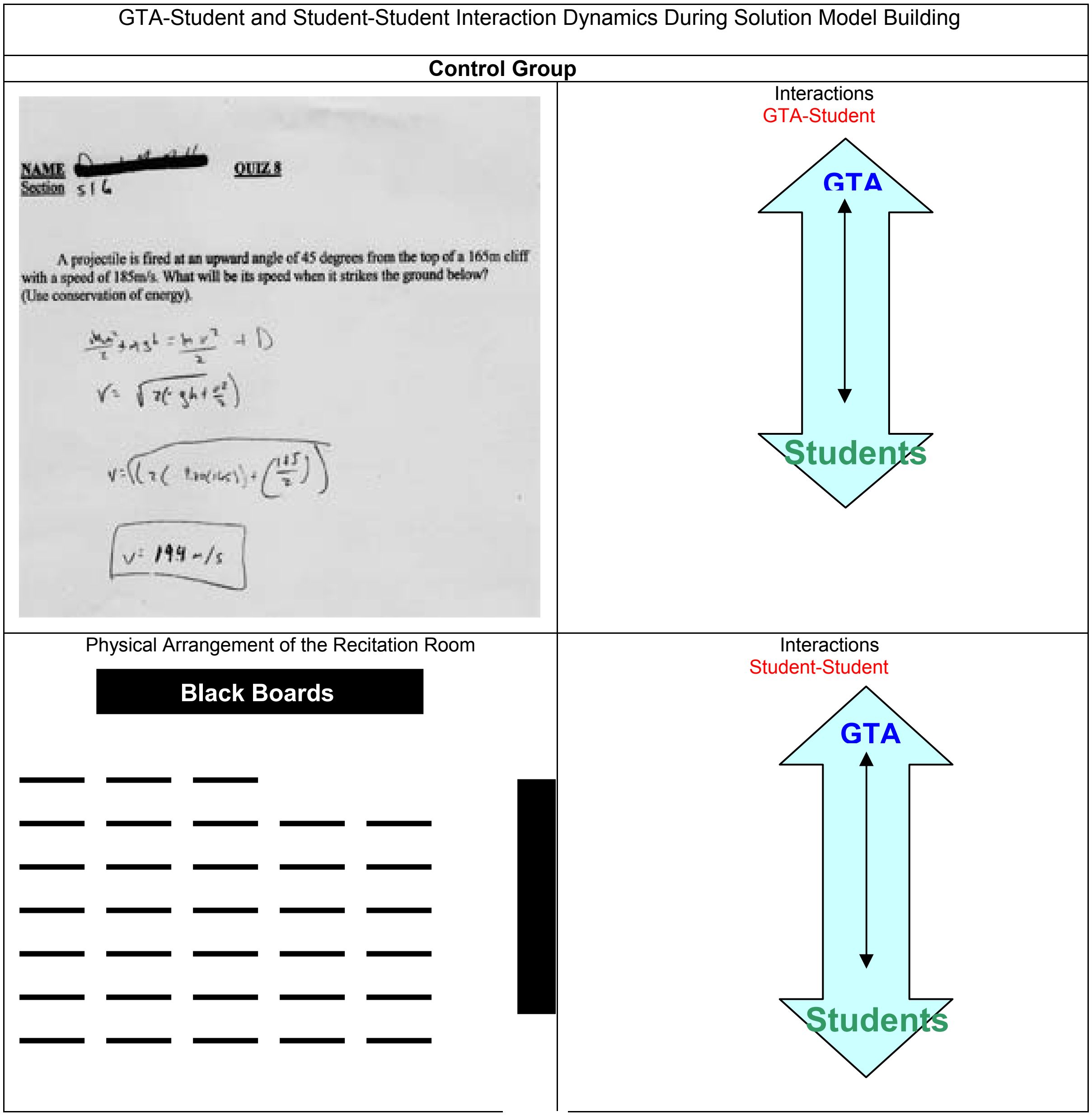


Figure 29 Control Group Recitation Problem

This occurred during the process of student model building and problem solving as outlined by the Cognitive Apprenticeship Model in Figure 30.

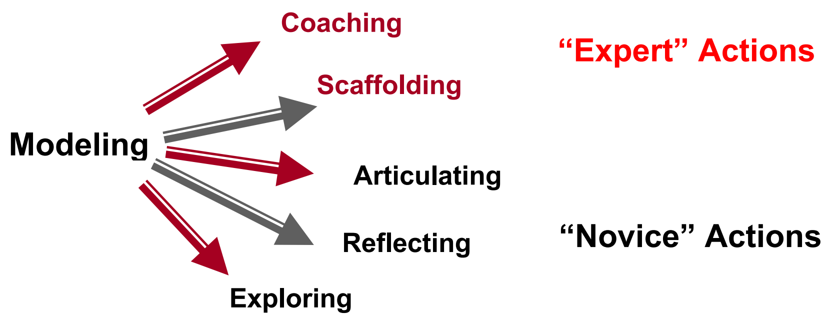


Figure 30 Cognitive Apprenticeship Model for Recitation Interactions

Treatment graduate teaching assistants (content experts) were engaged in coaching and scaffolding (guiding and supporting) the learning of physics students (content novices). Students articulated and reflected the process while building solution models during the context-rich problem scenarios with their teams. During typical control group recitations, the GTA lectured to the students who occasionally asked questions in a traditional format. Results of the video analysis were tabulated for the treatment and control GTAs and graphed. See *Figures 31a – 31f* for the treatment GTAs and Figures 31g – 31l for the control group GTAs. Inter-rater reliability on the RTOP had been previously established both by a second local researcher and by researchers that were nationally known. The scales on these graphs are based on the RTOP categories for traditional and reformed physics instruction, previously established.

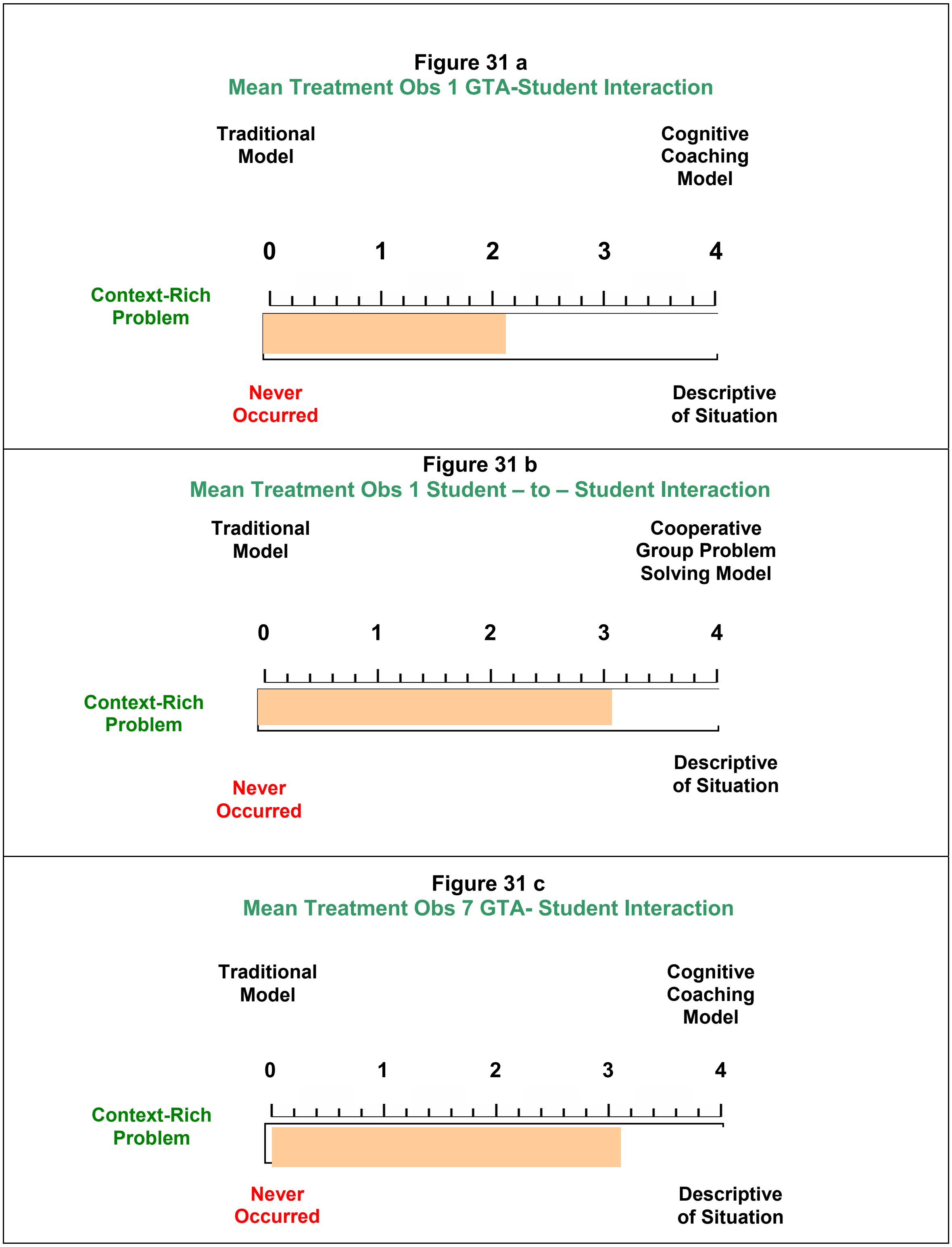


Figure 31 Student-to-student and Student to GTA Interactions

Figure 31 d
Mean Treatment Obs 7 Student – to – Student Interaction

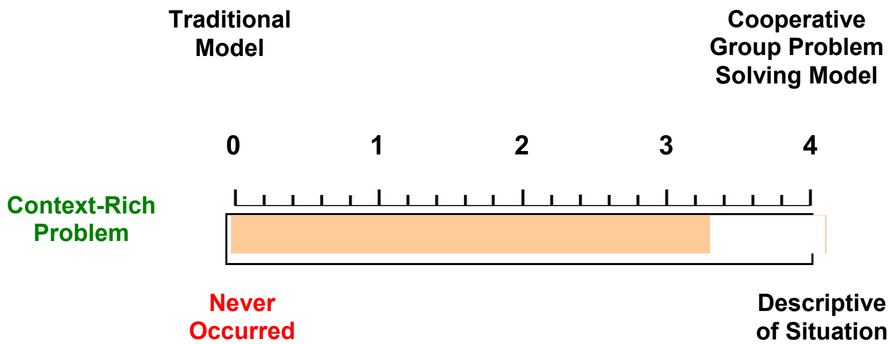


Figure 31 e
Mean Treatment Obs 14 GTA-Student Interaction

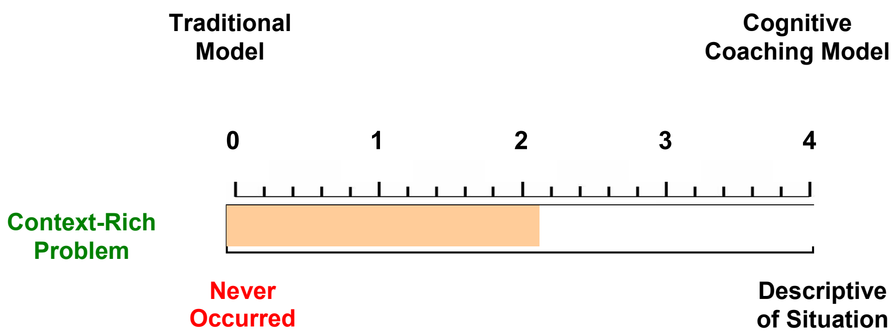


Figure 31 f
Mean Treatment Obs 14 Student – to – Student Interaction

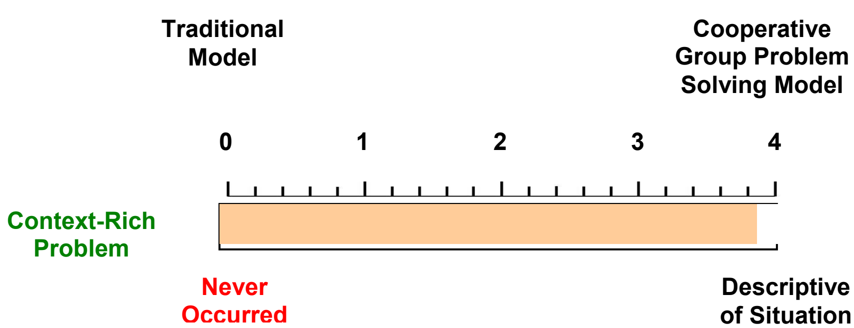


Figure 31 Continued

Figure 31 g
Mean Control Obs 1 GTA-Student Interaction

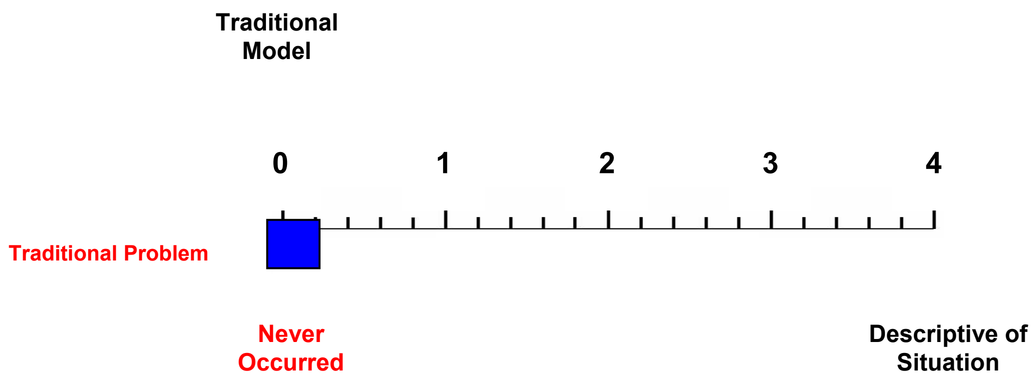


Figure 31 h
Mean Control Obs 1 Student – to – Student Interaction

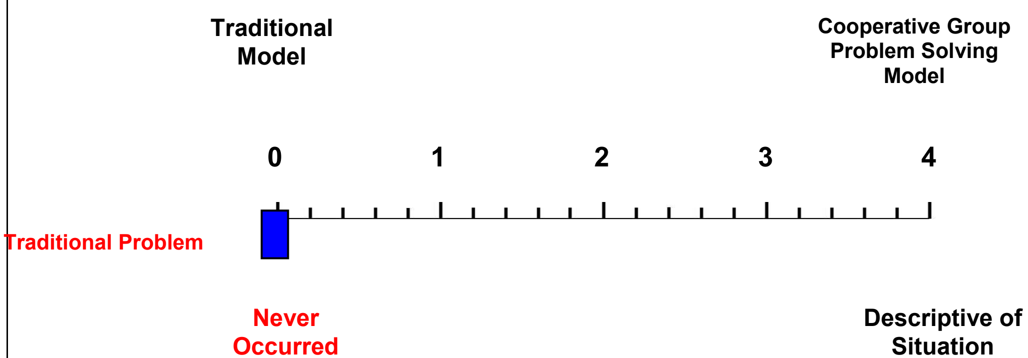


Figure 31 i
Mean Control Obs 7 GTA-Student Interaction

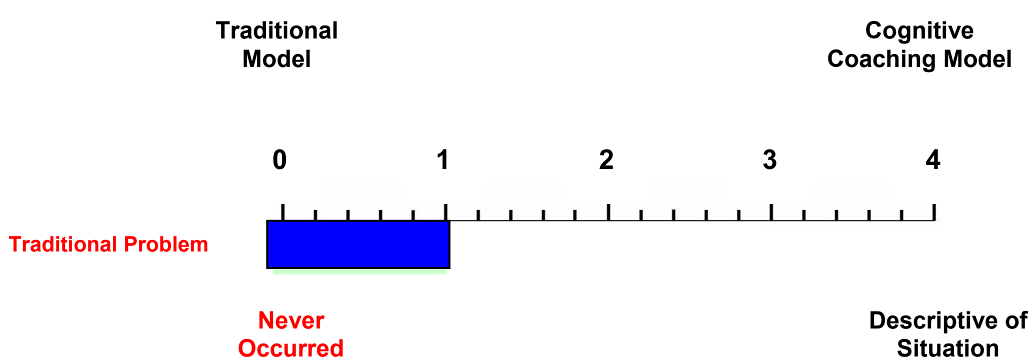


Figure 31 Continued

Figure 31 j
Mean Control Obs 7 Student – to – Student Interaction

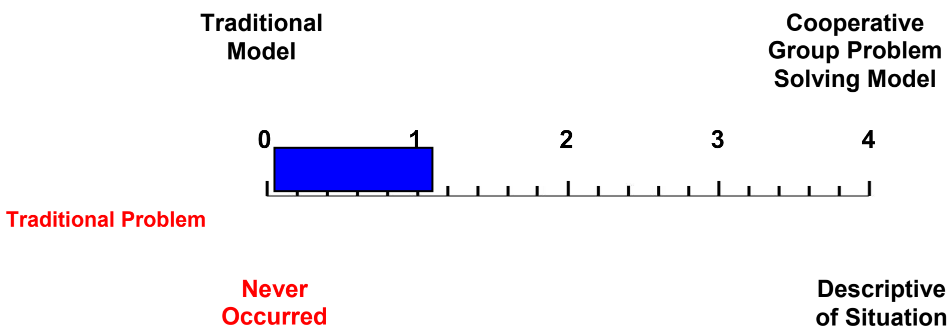


Figure 31 k
Mean Control Obs 14 GTA-Student Interaction

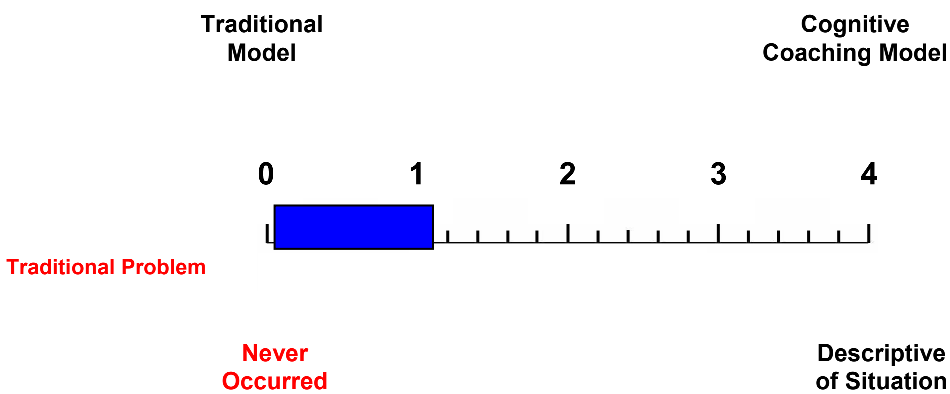


Figure 31 l
Mean Control Obs 14 Student – to – Student Interaction

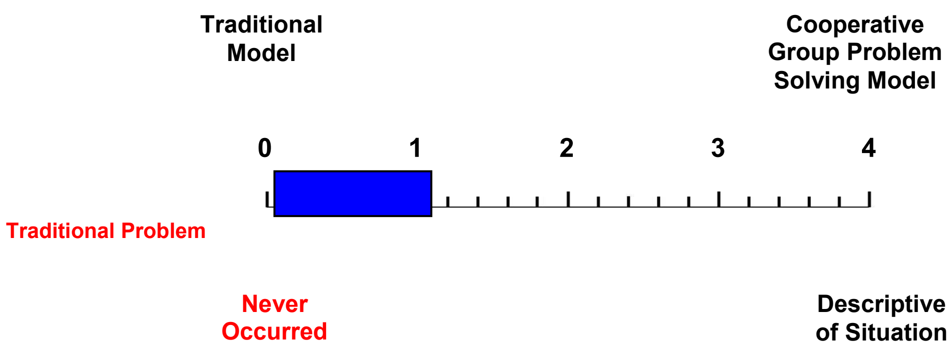


Figure 31 Continued

In the sampled video transcripts, the interactions between graduate teaching assistants and their students reveal the evidence of application of the cognitive coaching model (treatment) and traditional interactions (control). Note the dialogue between GTA and students, as they engage in cooperative group problem solving and build solution models, as well as between students. See Tables 30 and 31 for unstructured interview comments. Observations 1 and 7 are sampled and the progression of thought, between expert and novice, fruitful or not, shows a striking difference in the scenarios between the students and GTAs for treatment and control groups. The process of cognitive coaching is evident throughout the treatment examples, and is absent almost entirely from the control examples, even over time.

Student interactions with each other and the GTA are evidence of the application of the Cognitive Apprenticeship model.

Table 30 *Treatment Groups' Transcripts of Student Comments during Solution Model Building in Recitation Observations 1 and 7*

1: CPQ “Iceberg Problem”

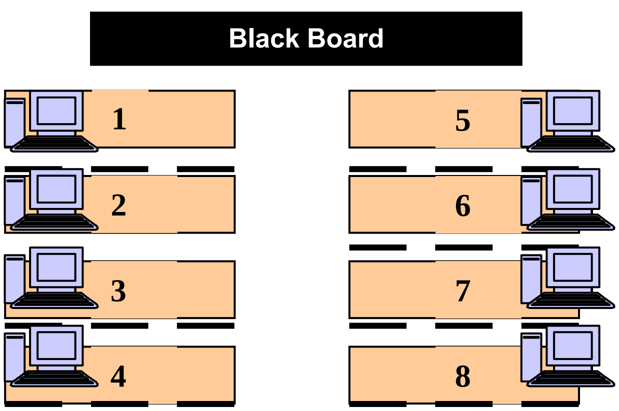
GTA “ A”	GTA “B”
S1: “We can’t figure out….” **GTA:** “So what force do you want to act?” **S1:** “Just the one that produces velocity.” **GTA:** “Initial velocity is not a force. So, unless something is actually pushing….” **S1:** “Right, okay.” “Any time something is in free fall, what happens?” **S2:** “So only g is the acceleration. **GTA:** “Good.” **Researcher:** (Most students paying attention during solution), Room Arrangement for Treatment Groups  	**GTA:** “This is about your problem…okay so….” **S1:** “I found out the time it would take to travel 15 miles for the whole trip …to travel 2 miles…8 minutes to get to point A to hitting the iceberg.” **S2:** “Eight minutes.” **S1:** “It takes five minutes to get the signal,” **S3:** “How long would it take to go two miles?” **S1**: “Up to eight minutes to hit the iceberg and.” **S2:** “Displacement below V1 and V2, travel time would be… draw this and it would take an hour to go 10 miles.” **S1:** “What is this? We can’t find the time.” **GTA:** “Ok, so you have 5 more minutes.” **S2:** “Go to the starting point and make that zero.” **S1:** “And then we have to equate it…oh, ok. Let’s do it in a different way….” **S2:** (Looks confused, turns to S3 and shrugs). **S1:** “Five minutes from the pond to reach the ship.” **GTA:** “Ok, you are on the right track.”

Table 30 *Continued*
7: CPQ “Vacation Breakdown”

GTA “ A”	GTA “B”
Researcher: (GTA starts out more traditionally with student supplying answers as she solves a problem from the homework), **GTA:** “We are looking for the acceleration of the rope…then?” **S1:** “The force is the same on all of the rope.” **GTA:** “Is anyone confused? Any questions? What do you need?” **S1:** “What is the ‘force of friction’?” **GTA:** “It is due to…?” **S2:** “The normal force acting on a surface.” **Researcher:** (CPQ starts here): **GTA:** “Okay, yes…?” **S2:** “We don’t understand how the tension is” **GTA:** “The tension is wherever the force is applied.” **S1:** “The friction is going back the other way.” **S2**: “With the tension going down like that, do we have to find the fiction force?” **GTA:** “Look at your free-body diagram. What is happening? Where is the motion? The force? So….” **S2:** “I have to look at the forces separately and I have to find the tension in the x direction.” **S3:** “That’s so the acceleration is where the direction of the force is.” **S2:** “It started at zero.” **S3:** “We can just keep it in mph, etc. everything is in the English system.” **S1:** “Ok.”	**Researcher:** (GTA starts out more traditionally with student supplying answers as she solves a problem from the homework), **CPQ Starts Here:** **GTA:** “Do you know what is needed?” **S1**: “I am drawing the free body diagram and labeling it so….” **GTA:** “And then what?” **S2:** “We can see whatever the sum of the forces are?” **GTA:** “What is the limit?” **S1:** ”Of the system?” **GTA:”** Yes?” **S2:”**Well maybe mass?” **S1:”**Have we learned tension before?” **S3:”**We need to see if the tension will exceed this.” **S1:** ”Yeah” **S2:”** Tension is equal to…voila, we got our tension, right?” **S1:”**Did we get it?” **S2:”**Well, let’s see….I is going to draw it.” **S3:”**”Let’s see where the tension is.” **S2:”**Let’s call this one the normal force.” **S3:** “Why are there two tensions on the rope?” **S2:** “I think I’ll let you handle this. That other way we did it was too easy, not right.” **S3:** “Weight equals mass times acceleration, plus the friction.” **Researcher:** (S1 observes and points but is not talking). **S3:** “Normal force is 2000 times 9.8 plus friction coefficient which is the normal force.” **GTA**: “What is the normal force? Make your equations separate.” **S2:** “My diagram looks like (epithet omitted)….” **GTA**: “What is your next step?” **S2**: “I need to sum all the forces in the x direction. Doesn’t this have a forward force?” **GTA**: “You know the energy conservation laws…” **S2:** “Don’t we have…there is too much information.” **S3:** “So you got to find the force.” **GTA**: “Focus on the tension and see what happens.” **S2:** “55 mph is the velocity.”

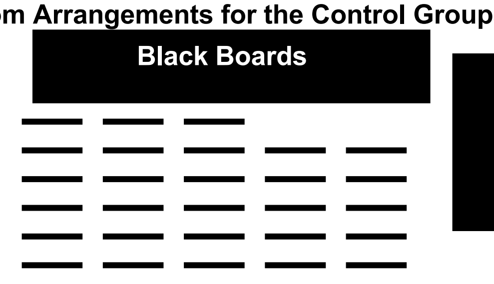
The transcripts of these recitations show that the GTA is using a traditional approach with students.

Table 31 *Control Groups Observations*

1: Traditional Homework Problem

GTA C	GTA D
GTA: “I just want to show you this, how to get one equation by integrating another. Look at the formulas in the book. I want to show you where it comes from. Let me show you how to substitute these into the equations…. Any questions over homework problems…? Do dimensional analysis, when you don’t know the formula.” **S1:** “Do number two and three.” **Researcher:** (Many students not paying attention during solution),	**GTA:** “What other questions? If you don’t have questions, I have some.” **S1:** “Number two, please…and number six.” **S2:** “Number seventeen.” **GTA:** “Number seventeen is important. There are words I used here – velocity and speed. And one-dimensional problem. What is the answer?”

7: Traditional Homework Problems

GTA C	GTA D
GTA: “Try to avoid just plugging in the numbers. Newton’s Laws are very important…Did he (the professor) cover chapter 6? 7?” **S1:** “Yes.” **GTA:** “(This homework problem is a) great qualitative problem, not very different.” **S2:** “Problem number 3, Chapter 7?” **GTA:**”Yes, it is a hypothetical planet with the same mass as Earth and but with a radius of 2.5 times….It is good to compare what g is on another planet.” **Researcher:** (GTA Works problem without student input). **GTA: “**Can anyone just plug these numbers into a calculator to get the answer?” **S3:** “Where did $\mathbf{r_e}$ come from?” **GTA:** “That is the radius of the Earth. What number did you get for the answer? .6 g?” **Room Arrangements for the Control Groups**  	**GTA:** “We will talk about circular motion and friction, today. Two kinds of friction in this chapter, one of them is static and the other is?” **S1:** “Kinetic.” **GTA:** “Can you talk about where it is?” **S2:** “I am trying to put it as if it didn’t have any friction.” **S3:** “If it doesn’t…it overcame □ N, then it is static.” **GTA:** “If you have a box, it must overcome a force “F.” Then the box moves a little, but…” **S4**: “F = □ N.” **S5:** “If the surface is horizontal.” **GTA:** “If this force is equal to 0, the object moves.” **S1**: “Force of friction only happens when you push. Whatever your force. □is proportional.” **S5:** “to N.” **GTA:** “There is no sense in talking about □You can say the object moves relative to the surface…. “ **S1**: “As long as the force is…?” **Researcher:** (GTA lectures for the rest of the recitation, no more student input or comment).

Student comments made during recitation reflected on the problem solving and are offered as additional evidence of the distinction between methods applied in the treatment group as contrasted with the control group in this study. These comments can be seen in Tables 32 and 33.

Table 32 *Treatment Group: Student Unstructured Interview Comments*

S1: “We made connections with the help of our group members and TA that resulted in a better understanding of the problem.”
S2: “We were encouraged to compare our problem to other examples in the real world, the lab and the homework.”
S3: “Solving these problems requires that our team sometimes disagrees (my partners were forced to apply a free body diagram) but in the end we understand the concept better.”
S4: “Our TA gave us a different idea for the problem than the one we were using, only after we thought about the problem and tried solving it by ourselves.”

Table 33 *Control Group: Unstructured Interview Comments:*

S1: “My TA tries to help. But, he does it differently than the professor and then I can’t relate it to the homework and my quiz grades are very low.”
S2: “Our TA cares about us and wants us to do well. But, he has gone beyond us and has trouble explaining it.”
S3: “I like this class but it takes a lot of time and I don’t have enough time to do a good job, especially on studying for tests.”
S4: This is a waste of time; I can’t get my questions answered. The TA can’t explain anything and just confuses me.”

Summary

A comprehensive look at the results of the measures applied during this study in terms of the research questions posed was attempted in this chapter.

While some quantitative and qualitative evidence were consistent in supporting the question of whether GTA's adhered to the cognitive coaching model, during recitation some data such as MPEX2, Part II, was inconclusive. The MPEX2, Part II, as a measure of the GTAs' understanding of the nature of physics teaching showed data that was mixed and reflected individual GTA differences as compared with qualitative measures such as the interview data.

The RTOP data showed that the treatment GTAs, although using more reformed methods initially, improved markedly over the semester compared with the control GTAs who had more room for improvement but made little progress.

Students in the treatment sections and their GTAs had more frequent interaction and followed the reformed teaching model on measures of conceptual understanding: the FCI and FM2CA. Transcripts of the video observations yielded a difference in student and GTA understanding of the problem-solving methods used.

In Chapter III of this dissertation the design; tests and measures were delineated. Also in the previous chapter, the model was outlined and defined. A brief discussion of the results of the application of this model and the impacts on the treatment GTAs' sections as compared with the outcomes in the control GTA's sections was discussed in this chapter.

Areas of interest for further study, discussions and implications of the EMIT model, the data from this study will be discussed in Chapter V.

CHAPTER V

DISCUSSION, CONCLUSIONS AND IMPLICATIONS

> To be prepared against surprise is to be trained. To be prepared for surprise is to be educated. Education discovers an increasing richness in the past, because it sees what is unfinished there. Training regards the past as finished and the future as to be finished. Education leads toward a continuing self-discovery; training leads toward a final self-definition. Training repeats a completed past in the future. Education continues an unfinished past into the future.
>
> − James P. Carse, *Finite and Infinite Games*

Research Questions

1. To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?
2. What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?
3. What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Introduction

In the previous chapters, the explicit nature of the EMIT model for pedagogical instruction and impact of that instruction on physics graduate teaching assistants' teaching have been described, measured and analyzed. This study used both quantitative and qualitative methods in order to gain an understanding, gleaned from examining, on several measures, 1) GTA adherence to the EMIT model during recitation, 2) the impact of the EMIT model on treatment GTA beliefs about the nature of physics and physics problem solving. Also examined were students' 1) conceptual grasp of the basic principles of force and motion as they solved problems in cooperative groups (treatment) and traditionally (control) during recitation, 3) attempts for treatment groups to become more expert-like in building solution models of complex problem scenarios and 4) overall performance, in the introductory first-year physics course compared to the control group. Application of the EMIT model by treatment GTAs and the resulting performance of their students was examined and the data analyzed on several measures for observations 1, 7 and 14 against similar observations of the recitation activities for the control GTAs.

Undertaken, during the course of this study, was a process of explicit modeling of the methods expected for physics GTAs to use during instruction. GTAs were trained on the RTOP instrument so that they would be better able to understand the elements of reformed teaching upon which their teaching would be judged. The researcher modeled the methods of cognitive coaching, Socratic questioning and other strategies during instruction. The treatment GTAs were trained in reformed teaching methods in part by training on the RTOP while control GTAs received a copy of that instrument without training on it.

These methods drew upon previously successful studies and introductory physics reform research done at the University of Minnesota by the Heller et al. (1984; 1992; 1995; 2001), Redish et al. (1998) at the University of Maryland, Halloun and Hestenes (1992) at Arizona State University, Beichner (2004) at North Carolina State University and many others, nationwide.

In the next section the theoretical framework will be revisited. In subsequent sections, each research question will be reexamined, the data will be interpreted, and then the limitations of this study and its implications will be discussed.

The EMIT Model in Terms of the Theoretical Framework

Before drawing conclusions about the results found in this study it seems important to first revisit the theoretical framework upon which it was based. The impetus for the design of the EMIT model was not only based on the need for a specific program for physics GTA instruction but also on the need to synthesize methods applied for other purposes. This blending of methods culminated in tapping the ideas behind Giere’s (1997, 1999) multiple-representational (perspectival) model for conceptual understanding with a modified use of the Cognitive Apprenticeship instructional model (Collins et al., 1989; Collins et al., 1991; Collins & Duguid, 1999).

Underpinning this study was the application of Giere’s perspectival model in order to engage the student (through the GTAs’ application of the EMIT model) in a process of multiple representations. Problem solving using this method allowed the investigation of the context-rich problem through a more holistic process than traditional methods employ. The steps in this process of model building during problem solving can be found delineated in greater detail in Appendix D. In order to simplify this process, during recitation the problem scenario is broken down into manageable concepts and the real world is idealized. Then, as assumptions are made and the solution model is constructed, connections with the real world obviate the *concretization* of the problem. (The learner checks for reasonableness and correspondence of the model with the real world). Evidence that the student (novice) becomes more expert is revealed when he or she is able to apply a similar solution model to novel situations (Chi, Feltovich & Glaser, 1981: Driver et al., 2000; diSessa, 1988). . See Figure 32 for a simplified diagram of Giere's Perspectival Model.

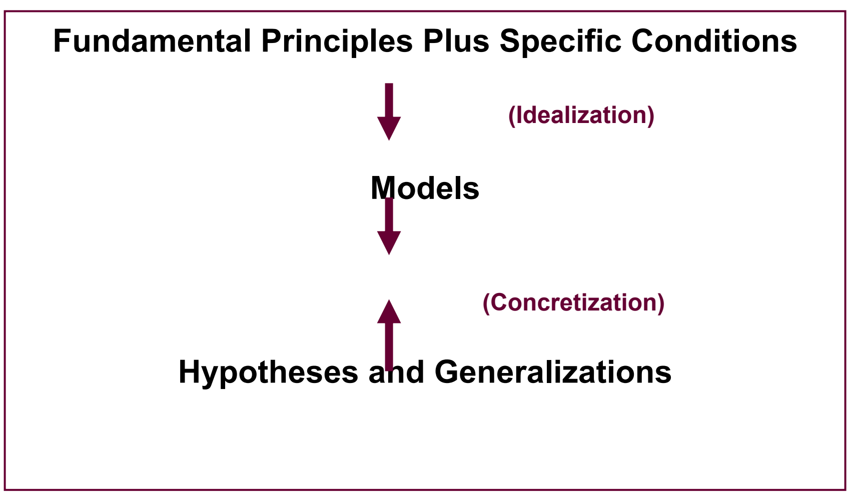


Figure 32 Giere's Perspectival Model

Expert (GTA) intervention was required to encourage the novice problem-solvers in the cooperative groups to negotiate a solution (Heller et al., 1992; Collins et al., 1991). The treatment graduate teaching assistants seemed to become more adept at the process of cognitive coaching over time even though they started out as applying more reformed strategies as can be seen in the RTOP and student data. The implications for these results will be discussed in the next section. Guidance by GTAs was performed through scaffolding with “fading” of support as students became more expert in their constructions (Collins et al., 1989). This process is shown in Figure 33.

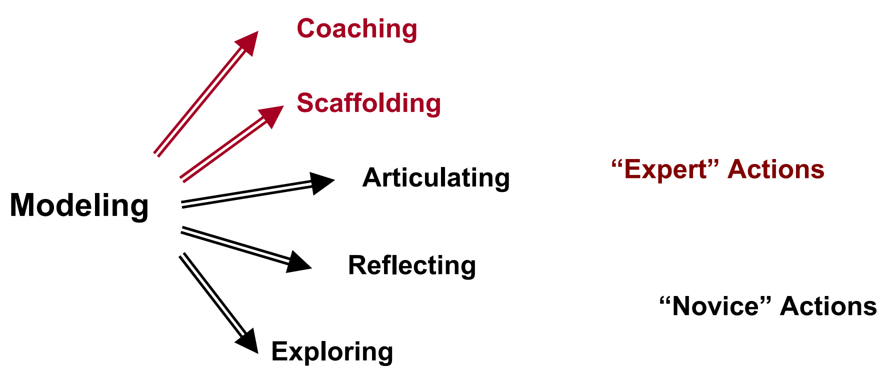


Figure 33 The Cognitive Apprenticeship Model

In this study, the GTAs modeled for and guided students through the process of cooperative group problem solving with the creation of solution models for content-rich problem scenarios, using the Cognitive Apprenticeship Model.

Discussion of Results in Terms of Research Questions

Research Question 1

To what extent will physics teaching assistants, instructed with explicitly modeled interactive-engagement techniques (EMIT), adhere to this model and apply it during physics recitation?

What Do the Quantitative and Qualitative Data Reveal?

Both the quantitative (RTOP, Video analysis and Student Survey) and qualitative data (Student Survey Comments) supplied evidence to support that adherence to the EMIT model by the treatment GTAs, in contrast to the traditional teaching of the control GTAs, translated into a positive change from more traditional teaching style by the treatment GTAs to a more reformed approach as is delineated in the literature. This was also defined by the RTOP instrument and directly modeled in this study. Shown in Figure 34 are individual differences and similarities between GTAs in the treatment and control groups compared with their scores on the observation video scores at weeks 1, 7 and 14. Assessment of interactions problem solving was done for both the GTA-student interactions during recitation as well as the student-student interactions,

The results of student evaluations of GTAs on the Student Survey and coding of the video of the GTA-student and student-to-student interactions for the treatment group showed that GTAs:

- Respected students' naïve conceptions while acknowledging their prior learning, creating an environment that engaged students in active cooperative problem solving as evidenced by student responses on the Student Survey, items 1, 2, 5, 12 and 18. Student Survey Scores for the treatment GTAs increased on these items by 15 percentage points for TA "A" and 13 percentage points for GTA "B." RTOP increases were 36 percentage points for GTA "A" and 32 percentage points for GTA “B.” Additional supporting data was provided by student comments in Table 34.

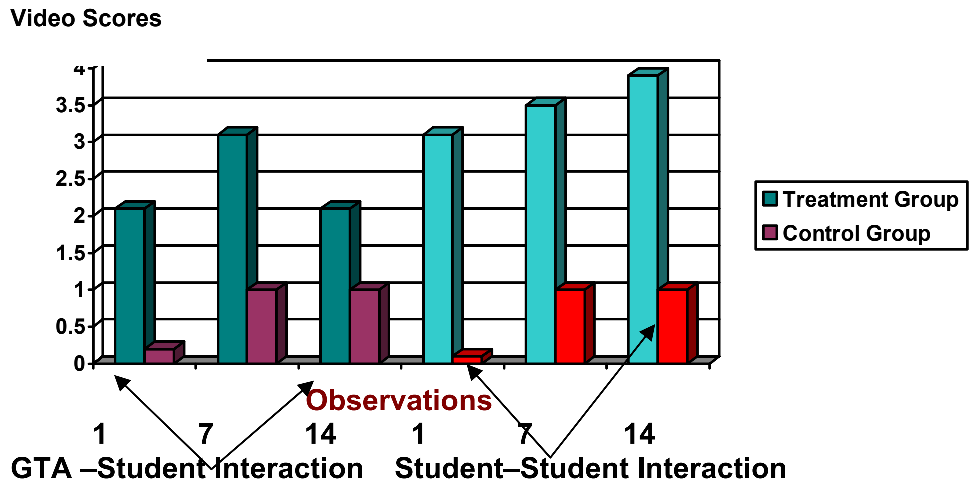


Figure 34 Comparisons of GTA and Student Interactions

- Encouraged and validated student ideas using Socratic questioning (Hake, 1998) This was done during cooperative group problem solving, guiding students as they began to move from novice to expert-like understanding of the fundamental concepts of physics as evidenced by student responses on the Student Survey, items 3, 7, 11, 14 and 16. Student Survey Scores for the treatment GTAs increased on these items by the same margin as for items above and student comments further support these occurrences can be seen in Table 34.
- Interceded only when students became stuck, offering only enough help to allow students to begin again make progress – Just-in-Time intervention. Evidence for adherence to model are reflected in the

RTOP scores, GTA MPEX comments (see table on page 170) and the interactions data seen in Figures 31a – 31 f in Chapter IV.

- Expected divergent modes of thinking among students while providing guidelines for individual student contributions and active responsibility as student questions shaped the focus of discussion during the problem solving in recitation. Evidence for adherence to model is reflected in the treatment GTA increased RTOP scores compared to the control GTAs and Student Survey scores on items 4, 15 and 17. Additionally, treatment GTA “A” moved from a score of 0.50 to 3.75 on the RTOP-like nature of physics and physics teaching scale and treatment GTA “A” moved from a score of 0.10 to 3.75. These scores are contrasted with the control GTAs whose scores increased from 0.20 to 2.0 for GTA “C” and from 0.20 to 1.0 for GTA “D” (see Figure 19 in Chapter IV).
- Students built their solutions by negotiating with each other and encouraging explicit descriptions of the physical situation, stating assumptions, sketching and solving the problem. Evidence for treatment GTA impact can be seen in the Student Survey items 6, 8, 9, 10 and 13 and in student comments on the interviews as seen in Table 33 in Chapter IV contrasted with the student interview comments for the control GTAs as seen in Table 34 in Chapter IV.

On the Student Survey instrument, students assessed their GTA's instruction at observation 1, 7 and 14. Overall, the students in treatment GTA "A's" sections reported a 9 percent increase in their GTA's adherence to methods of interactive teaching as assessed by the Student Survey. Students in treatment GTA "B's" recitation sections reported a 12 percentage point increase on the same measure. In the control sections, GTA "C's" students reported a 3 percentage point increase, while GTA "D's" reported a 5 percentage point increase over the initial assessment in week 1. These results corroborate those found by the researcher on the RTOP. Treatment GTAs were, on the whole, more responsive to student's questions and increased this practice over time, interacted more with their students and stimulated novel applications to problem solutions learned. See Appendix A for a copy of the RTOP instrument whose items reflect these conclusions.

The Student Survey comments in Tables 34 and 35 below show the difference in student thinking about the degree to which their GTA interacts and directs problem solving during recitation between the treatment and control groups. In the treatment group, the student comments reflect the high degree of GTA-student and especially student-to-student interactivity involved in solving problems and building models. In the control group, traditional methods were shown to have been the methods by the control GTAs. The examples contrast treatment and control group GTA comments.

Table 34 *Treatment Group Student Comments about GTAs*

Treatment Group GTA "A"
S1, Observation 1: "I was encouraged to use alternative solutions by being given different [problems] from (but similar to) the ones discussed."
S1, Observation 7: "The focus was to be able to do complex problems and work as a group. The group members were encouraged to listen to each other's ideas and to ask the TA questions."
S1, Observation 14: S1:"to understand and solve problems that involve many types of knowledge in physics. Examples that are real world that were used included: car crashes and astronauts…."

Table 35 *Control Group Student Comments about GTAs*

Control Group GTA "C"
S1, Observation 1: "I followed the instructions. They told me what to do. I was not reflective about my problems. I did not think at all about my understanding."
S1, Observation 7: "**:** "Recitation is boring. The (G)TA usually just confuses people."
S1, Observation 14: "(The GTA's) knowledge exceeds his level of physics and it is hard for him to explain simple ideas trying not to use what he knows from his own studies."

This sample of both treatment and control group students' comments suggest greater satisfaction with the methods, used in the treatment group.

Research Question 2

What is the effect of the EMIT model on the graduate teaching assistants' understanding of the nature of physics and physics teaching?

Beliefs are tenacious, tightly held and resistant to change (McDermott, 1984; Carey, 1985; Hewson, 1992). In this study, a measure of the GTAs' beliefs about the nature of physics changed little from pre to posttest (MPEX2, Part I), with only the international students' beliefs changing at all.

What Do the MPEX2 and GTA Interview Data Reveal?

There was a 9 percentage point change for the international GTA in the treatment group, with no change for the GTA from the United States. There was a 7 percentage point change for the international GTA in the control group, with no change for the control GTA from the United States. International GTAs expressed, during interviews and on the comment sections of the MPEX2, that they had never had experience with reform teaching methods, and as a student or as an instructor, were unsure about how to apply and value these methods. Treatment GTA "B" expressed during the post interview that he was "very convinced" that the cooperative group methods were best for students and that he "would use them more in his teaching" during subsequent semesters. See also Figure 35 for a comparison of the means for the normalized MPEX2, Part II scores for the treatment and control GTAs' views about the nature of physics and physics teaching. The treatment GTAs, once familiar and comfortable with the interactive-engagement methodology, seemed to prefer the interactivity to the traditional lecture format and claimed that students seemed to grasp the basic concepts better and paid more attention in recitation compared to the comments made by the GTAs in the control group. Evidence for these claims can be seen in the transcripts of the pre and post interviews and MPEX2 comments found in Chapter IV, Table 21 and Table 19.

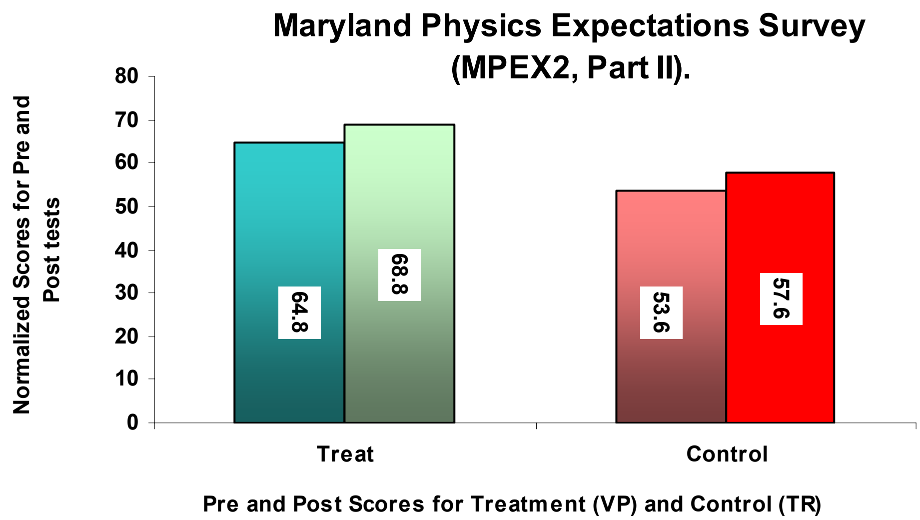


Figure 35 Normalized MPEX2 Scores, for Treatment and Control GTAs

On the MPEX2 the scores were shown (see Figure 33) to be non-equivalent for both treatment and control groups with the treatment GTAs' pretest and posttest scores approximately 11 percentage points higher than the control GTAs. During pre and post interviews, both treatment and control GTAs reflected on their conceptions of the nature of physics as well as their conceptions about physics teaching itself. When coding and combining these qualitative data with the quantitative RTOP evaluations, a pattern of growing maturity about the nature of physics on the part of the GTAs is then revealed. Evidence is given in the representative comments made by one of the treatment and one of the control GTAs, shown in Table 36.

The treatment GTAs' concerns move from, "How will it affect me?" at the beginning of the semester, to, "How can I make this method work more effectively, by modifying it?" at the end of the semester. In the control group, the GTAs statement reflect more concern about class management issues and puts the onus for learning directly on the student, with no comment about cooperative interactions. Comments on the MPEX2 by the treatment and control GTAs

Table 36 *MPEX2, Part II. GTA Comparative Reflections Treatment and Control*

Timeline	**Treatment: GTA "A" Comments**	**Control: GTA "C" Comments**
Instruction Week	• "I worry that students may not respond to group work or pre-recitation assignments. • What is the main difference between the new approach and traditional education? Is this really effective?" • "I worry that the weak students will get lost in the class activities and I feel a little useless, letting students control much of what goes on in class." • "Is it fair to give everyone in the group the same grade?" • "I am beginning to be a little concerned about my work load." • This workshop (instruction) was very informative. I feel like I understand *much better* now what *exactly* we are trying to effect in the classroom."	***Researcher Note: Control GTAs did not receive instruction.***
Observation 1	• ""Students don't respond, when I pause for them to ask questions. I have to drag it out of them."	"I don't know how to keep students from talking at the same time?
7	• "We need more time to answer student questions. The students need more time to do the context-rich problem."	"Students don't seem to be able to follow the math. I think that they are not doing the homework,""
14	• "When I try to write these (CPQs) problems, I can see how they are different from the homework problems. The students aren't held responsible for these on their exams."	"Students are paying more attention, especially when they have a test or just took a test."

Table 37 *Samples of Pre and Post MPEX2 Comments by GTAs*

Researcher Comment: *These comments reveal that treatment GTAs are concerned with applying the method, during problem solving, as illustrated in the following comment:*
Pretest: GTA "B": "Must understand to really solve a problem correctly."
Posttest: GTA "B": "Lecture doesn't always give a deep understanding or knowledge how to apply concept."
Researcher Comment*: The control GTAs were most concerned about "needing the right formula" and "correct is best:"*
Pretest: GTA "C": "Thinking will give the students more understanding, after the lecture."
Posttest: GTA "C": "Most students rely on lecture only to get the information and don't practice problems or think."

reflected a widely different attitude about the purposes of instruction and its design as is evidenced in Table 37.

The degree to which GTAs engaged in interactive-engagement with students, and student-to-student interaction occurring during instruction, was assessed on a five-point scale, and based on the RTOP instrument, at observations 1, 7 and 14. As shown in Table 38, these additional observation data were compiled for the treatment and control GTAs and compared.

Treatment GTA comments and concerns were voiced as well as written at the end of each day, during GTA instruction week, and were also sampled at video observation 1, 7 and 14. Control GTAs voiced concerns during the video observations as well as during the pre and post interviews. Examples of these comments can be found in Chapter IV, Table 20.

The comments reflected an easing concern by the treatment GTAs, as they gained and practiced the interactive-engagement skills. Control GTAs' comments remained similar throughout the observation time span. Taken along with the modest quantitative evidence, it appears that practice and skills, gained through instruction, enhanced the treatment GTA's comfort with the cognitive coaching methods and interactive-engagement problem-solving process. These qualitative data augment the quantitative data reflected in the RTOP scores as well as the comments made on the MPEX2 and on the semi-structured interviews.

Table 38 *Degree of Interaction during Observations, Coded from Video**

GTA	GTA –Student Interaction			Student-Student Interaction		
	Observations			Observations		
	1	7	14	1	7	14
Treatment Group	2.1	3.1	2.1	3.1	3.5	3.9
Control Group	.2	1	1	< 0.1	1	1

*A scale of 1-5 is used, based on the RTOP evaluation instrument items, especially items 11-20. Students became more engaged with each other, during problem solving than with the GTA, over time in the treatment group.

Research Question 3

What is the impact of the EMIT model on physics undergraduate students' conceptual understanding of force and motion during the problem solving process?

Heller et al. (1992) encourages a continuous interaction during problem solving between instructor and student as well as between students in order to stimulate students to reflect on their learning. These results corroborate previous studies where the recognition of, discussion about and validation of students' naïve conceptions were found to be necessary before meaningful conceptual change could take place (Larkin et al., 1980, McCloskey, 1983; Minstrell, 1984, Schoenfeld, 1985; Roschelle; 1991; Sternberg & Horvath, 1995, Minstrell, 2001).

Implications of Discriminant Function Analysis Results

The data for the first research question suggest that the treatment and control GTA's, while beginning the semester with different scores on the RTOP instrument, at the end of the semester (at Observation 14) the treatment group improved markedly while the control group scores reflected little progress. These same results were borne out in students' assessment of the GTA's methods (Student Survey scores) and in the students' Final Course Grades.

The three measures that provided the criterion variables for a four-group Discriminant Functional Analysis test were 1) the Final FCI scores, 2) the Final Student Survey scores, and 3) the final course grades. DFA was then run in SPSS. The 4-level test was used in order to discover if the Discriminant Function predicted group membership for each of the GTAs in the study. These predictions were done *post hoc*. For GTAs "A," "B,""C" and "D," The DFA function 1 predicted group membership in the GTAs' sections 57.1, 91.7, 68.4

and 46.2 percent of the time, making it the most reliable measure of differences between GTAs.

The DFA test results and *a priori* predictions for a new set of students, based on the same criteria as the cross-validation shows, are not in themselves convincing. These data show very mixed results for this test. (See Chapter IV, Tables 25 and Table 26 to review these data). It is incumbent on the weight of the supporting qualitative and quantitative evidence gathered concurrently, to show the correlations between GTA instruction, application of that instruction and student performance. Statistical significance is attained, for the DFA test as is shown by the Wilk's Lambda and the Chi-square values. The practical significance as shown in two tests of effect size will be discussed in a later section of this chapter.

Student performance from pre to post tests on the FCI was mixed with a modest improvement illustrated by the changes in the treatment group scores as compared to the control group, seen in Figure 36.

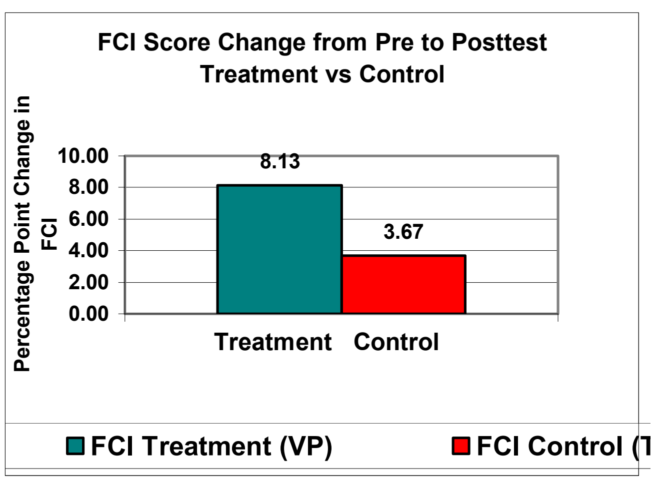


Figure 36 Change on the FCI: Treatment vs Control Groups

The data suggest that students as well as GTAs in the treatment group favored cooperative-group problem-solving methods over traditional methods and apparently performed better on novel problems on the FM2CA (a formative assessment), after having practiced on previous simulation problems. Student comments reported on the Student Survey as well as in the transcripts of the FM^{2}CA support this finding.

Exam scores were not used as a measure of student success, as there was no commonality between exams from one professor to another. As an example, one of the treatment professors even changed his exam style from exam to exam. And, inclusion of the context-rich problems on exams was uneven and almost nil for one professor. Also, GTAs had no impact on the structure or content of exams. So, final course grades were used as a measure of overall student success in the introductory Physics 218 course. The difference on final grades between treatment and control groups was most dramatic in the B, C, D and F ranges as shown in Figures 36 and 37. Treatment students' grades were one-third to one-half a letter grade higher than control group students' grades. Grades were reported (by professors whose sections were in the study) higher in the treatment group over previous semesters performance in the same course, according to the director who lead the Visual Physics project to reform the introductory calc-based physics, based on data gathered from the past three Fall semesters.

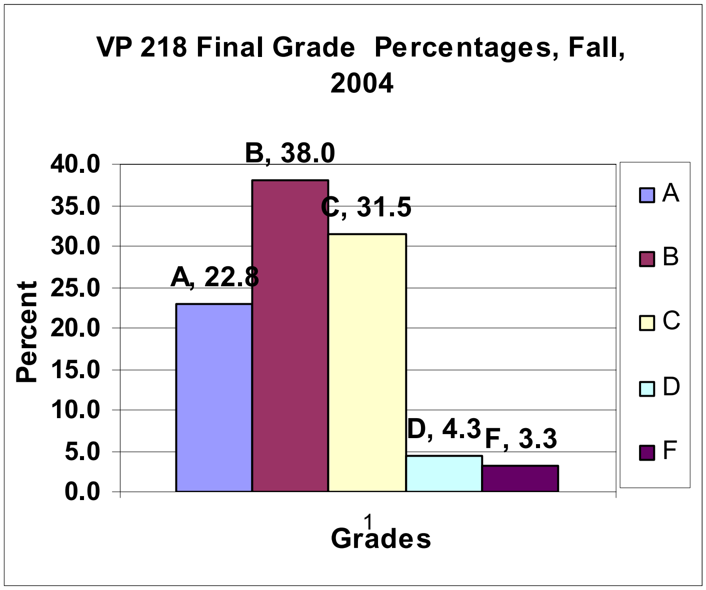


Figure 37 Final Course Grades Treatment

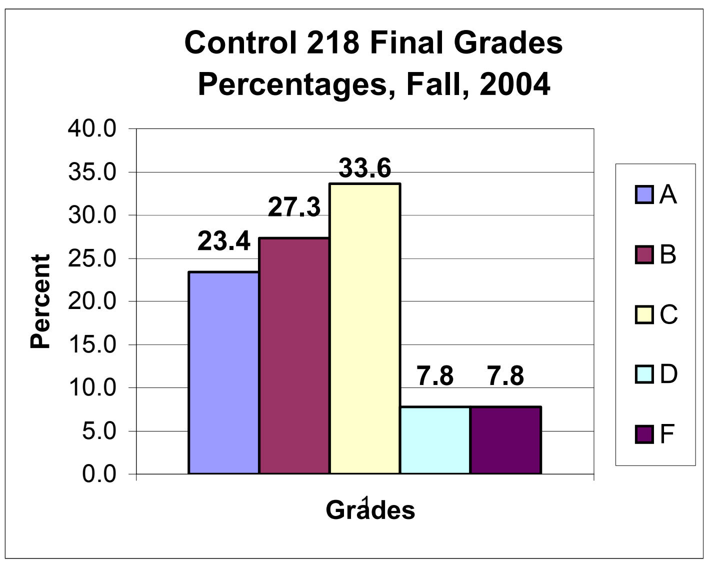


Figure 38 Final Course Grades Control

Undergraduate physics students' perceptions of the problem solving process can be qualitatively gleaned from the video observation data and the context-rich problems (CPQs) solved during recitation. The recitation quizzes were context-rich for the treatment group and traditional and linear for the control group. Samples of the student's thinking are revealed in the comments made on the Student Surveys and online simulation reasoning downloaded from the web.

Students in the treatment group asked more questions, more often and with more complexity than students in the control group. GTAs responded more frequently to student questions and encouraged more divergent thinking in the treatment group than did GTAs in the control group.

What Does the Effect Size Reveal about the FCI Test?

Subsequently, two separate tests to determine effect size (if there was a differential impact on the treatment and control groups) on the FCI data were performed in order to assess the practical significance of these data (Thompson, 2002). The value of Cohen's d, for the treatment group was found to be 0.408 (where >0.25 is considered significant) and for the control group was 0.149. This shows a modest impact of the intervention on the treatment group compared to a negligible effect on the control group. Another common measure of effect size, compared nationally in order to assess the degree to which a physics course has been "reformed" is the Hake gain. The value frog" (a fraction of the maximum possible gain on the FCI realized) is one of the quantities used to measure the effect of interactive engagement methods. The data shows a small gain (g ~ 0.2) for the treatment group and negligible effect for the control group (g ~ 0.1), reflecting the use of more traditional methods for the control group. See Chapter IV, Figure 25 for a comparison. The treatment group and the control groups' plots are at the lower edge of each band expected shown for reformed and traditional courses, respectively. In this project the Hake gain (g = 18%) in the treatment group, however, compared to the Hake gain (g = 9%) in the control group suggests a beginning in that direction

Limitations of This Study

It is important to note that a more encompassing course reform that articulates all elements of the introductory physics course – lecture, lab, homework, tests and recitation -- is required in order to produce an optimum impact on students' performance (MacIsaac & Falconer, 2002; Heller, personal communication, 2003; Beichner, 2004). Additionally, more positive changes between pre- and post-test scores on FCI would be expected if the exams included context-rich questions, as have been seen in more completely reformed introductory physics courses as was shown in Chapter IV, Table 15. Common sense dictates that, if students are to be given skills that are not tested, and, conversely, if they are tested on skills that they have not acquired, success on that test will be limited. GTAs' adherence to reformed methods should be further supported with all participants, professor, GTA and student espousing and following a coordinated method. Some further limitations of this study include:

- The procedure for selecting control and treatment GTAs was not strictly random. The requirement that the treatment GTAs be available for instruction, prior to the Fall Semester 2003, was a factor in selection. Subsequently, four graduate teaching assistants and their intact Physics

218 sections were chosen from a population of three Texas A&M physics professors, teaching in the Fall Semester 2003. Students registered for sections, unaware of any differences in the pedagogical structure of the treatment (VP) and control sections.

- The fact that random selection was not possible to accomplish in sampling for this study precludes any causal statements about the outcomes and limits the statistical tests that can be done. Rather, correlations and interrelatedness of both qualitative and quantitative data is revealed and explained.
- Technical problems arose that precluded the inclusion of more Diagnoser results. Similarly, WebCT access problems occurred and were resolved until three weeks into the semester, resulting in the exclusion of the VASS P-20 data – a measure of the nature of physics beliefs of undergraduate students.
- Missing data in the sample reduced the sample size in half for both treatment and control groups for use as the criteria for the DFA.
- The intervention is considerably shorter than is needed to produce long-lasting instructional change for GTAs, even though interventions continued throughout the Fall Semester, and continued before and during the Spring Semester 2004.
- Reforming only part of a course has mixed impacts on students, GTAs and professors. The articulation, instruction and practice with these

methods are needed for all players, long before implementation and during goal setting and design of the course.

- GTA sample size was very small, even though the supporting student sample whose data was used to corroborate results of the study conclusions was a reasonable size.

Future Implications and Applications of the EMIT Model

In future applications of the EMIT model, several modifications of the sampling techniques and design would be made, further extending the work done not only in this study, but incorporating other expert-novice findings and results of cognitive psychology and brain research.

Minstrell (1984) identified “targets for change” needed to help students learn physics. Further steps to fundamentally incorporate these targets into a refinement of the EMIT model could have a positive impact not only on instruction for GTAs but also subsequently on their teaching. The following elements should play a greater role in a revised EMIT model:

1) Increasing the use of Diagnoser or other assessment instruments that reveal specific areas of conceptual difficulty as well as the implications on instruction of students’ prior knowledge,
2) Implementing specifically designed tasks that reveal student thinking, empowering the instructor (with just the right tools) to intercede when students are actually in the process of altering their conceptions and incorporating new learning into their extant conceptual framework.

3) Making teaching expectations and goals of instruction even more explicit for GTAs and their students while shifting focus from the instructor-driven traditional lecture typically used even for recitation and putting it on a context-rich student-to-student interactive mode of instruction.
4) Expanding the modeling techniques for GTAs and teaching the lecture, lab and recitation with similar style in order to tap the power of proven reformed physics teaching elements.

An EMIT-like model extension could also generalize to other disciplines and grade levels by fostering the acquisition of the following problem solving skills:

1) Making connections between ideas well-defined and coherent, building explicitly on prior knowledge as an active process shared between instructor and student,
2) Highlighting the connections to fundamental concepts as students' questions arise and clarifying as concepts (and questions) become more complex,
3) Fostering, guiding and acknowledging an organized and coherent method of solution as students work forward from concepts as experts do, and

4) Evaluating formatively and interactively as progress is made while encouraging students to check for reasonableness as they build their solution models.

These elements of expert-novice research, coupled with the explicit nature of the EMIT model could be applied in the high school science and mathematics classrooms as well as other disciplines. Interactive assessment instruments (such as the FM2CA used in this study) that are valid, well-designed and that can give instant feedback as students are engaged in learning (K-20) could be a tool to help teachers to reveal student thinking, so that they might respond to and alter instruction, quickly. Applying the elements of a good design study (in actuality very much like the experimental designs of creative scientists) may further reveal unseen interactions and outcomes of the model that have not been possible with other research designs. Additionally, the effectiveness of traditional teaching methods for international GTAs has challenged large university physics departments nationwide, and is seen by many departments as a problem that has no solution (Jossem, 1999). Evidence from the EMIT model used in this study suggests that international and English-challenged GTAs and their students could benefit from the improved communication, close interaction and cognitive coaching methods integral to the EMIT model. Any future research study into the dynamics between GTA and student within the context of interactive-engagement strategies should use the elements of whole course reform. Impacts of small-scale reform efforts can be minimal and short-lived if not planned as part of a well-orchestrated and long-term reform effort. The explicit nature of these instructional methods, designed, synthesized and modeled for graduate teaching assistants in this study, could be applied to the lab very successfully (Heller et al. 1992).

Summary and Conclusions

The physics reform efforts of the last few decades have made great strides in highlighting the problems in traditional physics courses and demonstrated the need for course reforms. Heller et al. (1992) maintain that science concepts are incredibly tenacious and resistant to change. An effective change model must explicitly address the concepts to be changed with not only the instructor, but directly with the student. Implicit instruction has been shown not to markedly affect conceptual understanding, especially in regard to the nature of science (Lederman, 1999). Hestenes (1996) suggests that reinventing the way physics is taught through interactive modeling methods for students (as well as by and for GTAs) will impact positively the learning of fundamental physics concepts. Nationally, over several decades, numerous physics reform programs have been designed and implemented in recognition of and in attempts to remedy this problem. For a more complete discussion of the research in this area, please see Chapter II.

The physics department at TAMU had concluded that the traditional methods by which students learn introductory calculus-based physics were not optimal (McIntyre, personal communications, 2003, 2004). There was a consensus among instructors that course reform was necessary and agreement to a reform effort had been arrived at prior to this study.

Since physics graduate teaching assistants at TAMU as well as other large universities and in large enrollment classes typically spend as much “face time” with students as the professors do, and since students traditionally complain that they have difficulty grasping concepts and solving problems in physics by traditional methods, enhanced instructional and communication skills were desired to be taught to physics GTAs. GTAs graduate and move on to research, leaving the lessons learned behind. This fact further points out the need for a consistent and long-term application of this or similar instructional programs in order for these physics reforms to be tenacious. The EMIT model has attempted to demonstrate that there are qualitative differences among types of learning opportunities for both GTAs and their students. It is important to consider the individual differences of the GTAs as they learn and apply reformed methods. Further, if learning is a process through which novices become more expert-like in their thinking, then careful instruction of physics graduate teaching assistants in the skills needed to recognize these opportunities is warranted (Bruer, 1997).

The EMIT model seems to suggest that explicit instruction for GTAs can add a powerful new dimension to the reform of introductory physics instruction and impact student performance. Through the EMIT model, students were encouraged to communicate concepts while solving a content-rich problem with one another and their instructor, facilitating the learning of fundamental physics concepts while making the goals of physics recitation problem solving and model building explicit. Driver et al. (2000) described the process of developing models as one that helps to explain the world. During physics problem solving in-place knowledge was drawn on and students were encouraged to apply the skills learned to a new scheme or novel situation. Building a solution model during problem solving requires several representations if the problem is a concept-rich one. In the application of this model, the cooperative group process aided the student (with the guidance of the GTA) to fit the representative pieces into a conceptual whole. Tentative correlations could be seen between GTAs understanding of the nature of physics, the nature of the cooperative group problem solving process and the process of reformed physics teaching as a whole. Important new questions to answer about success of the EMIT model and reform teaching methods in other settings has been raised by this study.

After the Fall semester 2003, since the preliminary results of the study were encouraging (especially for students in the lower 3/4ths of the grade distribution) the Visual Physics (VP) project methodology was expanded to include twice as many sections of Physics 218 in the Spring 2004 and Fall 2004 semesters. It is expected that all Physics 218 sections incorporated the EMIT recitation model as part of the Physics 218 course redesign underway (with the approval of funding) by the Fall Semester, 2005. The research continues. Additional analysis of the data from this study will be undertaken in order to find new perspectives on the interactions that occur during recitation, between elements of the course and to further define and understand the role of the GTA in the introductory physics course.

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APPENDIX A

REFORMED TEACHING OBSERVATION PROTOCOL (RTOP)*

Daiyo Sawada External Evaluator
Michael Piburn Internal Evaluator

and

Kathleen Falconer, Jeff Turley, Russell Benford and Irene Bloom
Evaluation Facilitation Group (EFG)

Technical Report No. IN00-1
Arizona Collaborative for Excellence in the Preparation of Teachers
Arizona State University

I. BACKGROUND INFORMATION

Name of teacher __________ Announced Observation? __________ (yes, no, or explain)

Location of class __________ (district, school, room)

Years of Teaching __________ Teaching Certification __________ (K-8 or 7-12)

Subject observed __________ Grade level __________

Observer __________ Date of observation __________

Start time __________ End time __________

II. CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

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III. LESSON DESIGN AND IMPLEMENTATION

		Never Occurred				Very Descriptive
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2)	The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3)	In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4

IV. CONTENT

Propositional knowledge

6)	The lesson involved fundamental concepts of the subject.	0	1	2	3	4
7)	The lesson promoted strongly coherent conceptual understanding.	0	1	2	3	4
8)	The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4
9)	Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	0	1	2	3	4
10)	Connections with other content disciplines and/or real world phenomena were explored and valued.	0	1	2	3	4

Procedural Knowledge

11)	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0	1	2	3	4
12)	Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	2	3	4
13)	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	3	4
14)	Students were reflective about their learning.	0	1	2	3	4
15)	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	3	4

V. CLASSROOM CULTURE

Communicative Interactions	Never Occurred				Very Descriptive
16) Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17) The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18) There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4
19) Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4
20) There was a climate of respect for what others had to say.	0	1	2	3	4
Student/Teacher Relationships					
21) Active participation of students was encouraged and valued.	0	1	2	3	4
22) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	0	1	2	3	4
23) In general the teacher was patient with students.	0	1	2	3	4
24) The teacher acted as a resource person, working to support and enhance student investigations.	0	1	2	3	4
25) The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4

Additional comments you may wish to make about this lesson.

APPENDIX B

TAMU PHYICS GTA EMIT INSTRUCTIONAL SCHEDULE

Aug 26-29, 2003

Day I – Protocols -- Interviews/Testing/Instrument Analysis*

AM					
8:30-9:30	(I)	MPEX2	MPEX2	MPEX2	MPEX2
9:40 -10:40	MPEX2	(I)	DO	DO	DO
10:50-11:50	DO	DO	(I)	Control (TR) GTAs were interviewed On a subsequent day Control (TRs) do not get instruction/HW but take all tests	
PM					
12:50-2:30	(CRE) / (A-FCI)				
2:40-4:00	(RTOP)				
Homework:	Readings (1, 2)				

Day II – Protocols -- Discourse Management Dialoging/Questioning Strategies -

AM	
8:30-9:30	Discuss Homework Readings
9:40 -10:40	Structuring Discourse Management /Questioning
10:50-11:50	Acknowledging Pre-Conceptions/Providing “Just-in-Time” feedback
PM	
12:50-2:30	Concept/Content Rich Problems/ Acknowledging prior conceptions
2:40-4:00	Student model construction/ Progress Checklist
Homework:	Readings (3, 4)

Day III – Protocols -- Mock Recitation Videotaping and Analysis

AM	
8:30-9:30	GTAs assume the role of students as well as Instructor in A Mock Recitation Interactive Videotaping
9:40 -10:40	Critique of Teaching Video Model(s) (RTOP) Analysis of Video
10:50-11:50	Problem-solving Evaluation
PM	
12:50-2:30	Analyzing the Videotape of morning experience
2:40-4:00	Develop Model Lesson Plan for Physics Topic (Individually)/ Daily Progress Checklist
Homework:	Finish Plans, Readings (5,6, 7)

Day IV – Protocols -- Assessments/Group Interaction Strategies/Follow-ups

AM	
8:30-9:30	Discussion of Homework/ Presentations
9:40 -10:40	Critique and Discussion by GTAs
10:50-11:50	Flash-mediated Formative Assessments:
PM	
12:50-2:30	Assessing Group interaction strategies during Problem Solving
2:40-4:00	GTA Responsibilities and Weekly Follow-ups – CBAM instrument/ Progress Checklist

***Key:**

(I) Interview
MPEX2: Nature of Physics Conception Assessment
(DO) Diagnoser (online)
(IM) Intro to Co-operative Group Methods
(CRE) Analysis of student work -- Context Rich Examples
(A-FCI) Analyzing the FCI
(RTOP) Instructional Analysis
(JITT) Just in Time Teaching – online pre-recitation questions
CBAM – Concerns model for Reception to Change

(FM2CA) Formative Assessment Strategies

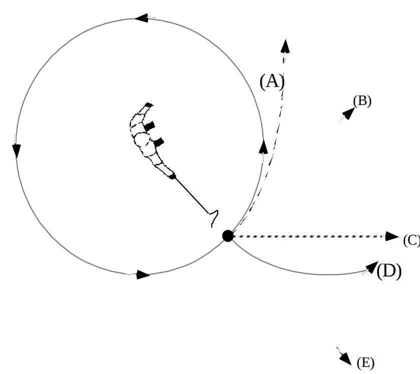
HW Assignments –

1. Reading on Student Naïve Conceptions
2. Reading on Research in Interactive Methods
3. Reading on JITT
4. Reading on Modeling Instruction
5. Reading on Socratic Questioning
6. Reading on Recitation Management
7. Reading on Conceptual Change Models

APPENDIX C

THE FORCE CONCEPT INVENTORY (FCI)*

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   (A) about half as long for the heavier ball.
   (B) about half as long for the lighter ball.
   (C) about the same time for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.
2. Imagine a head-on collision between a large truck and a small compact car. During the collision,
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car doesn't exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.
3. Two steel balls, one of which weighs twice as much as the other, roll off of a horizontal table with the same speeds. In this situation:
   (A) both balls impact the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
   (C) the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
   (D) the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
   (E) the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.
4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram below. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.



5. A boy throws a steel ball straight up. <u>Disregarding any effects of air resistance</u>, the force(s) acting on the ball until it returns to the ground is(are):
   (A) its weight vertically downward along with a steadily decreasing upward force.
   (B) a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
   (C) a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.

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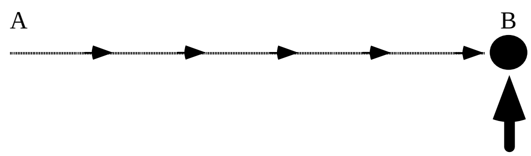
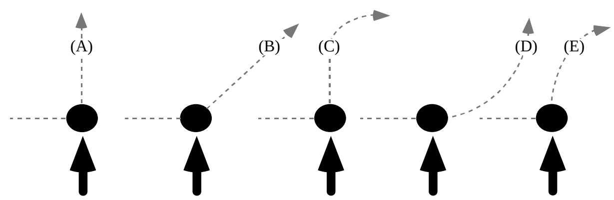
(D) a constant downward force of gravity only.
(E) none of the above, the ball falls back down to the earth simply because that is its natural action.

*** Use the statement and diagram below to answer the next four questions:**

*** The diagram depicts a hockey puck sliding, with a constant velocity, from point "A" to point "B" along a frictionless horizontal surface. When the puck reaches point "B", it receives an instantaneous horizontal "kick" in the direction of the heavy print arrow.**



6. Along which of the paths below will the hockey puck move after receiving the "kick"?



7. The speed of the puck just after it receives the "kick" is

(A) equal to the speed "v_o" it had before it received the "kick".
(B) equal to the speed "v" it acquires from the "kick", and independent of the speed "v_o".
(C) equal to the arithmetic sum of speeds "v_o" and "v".
(D) smaller than either of speeds "v_o" or "v".
(E) greater than either of speeds "v_o" or "v", but smaller than the arithmetic sum of these two speeds.

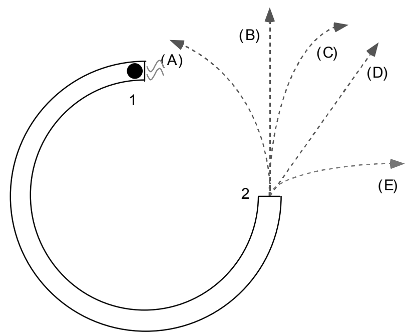
8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the "kick"?

(A) No change.
(B) Continuously increasing.
(C) Continuously decreasing.
(D) Increasing for a while, and decreasing thereafter.
(E) Constant for a while, and decreasing thereafter.

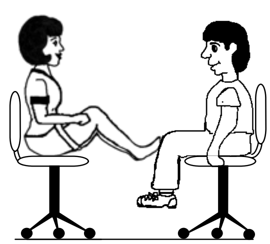
9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

(A) the downward force due to gravity and the effect of air pressure.
(B) the downward force of gravity and the horizontal force of momentum **in the direction of motion**.
(C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck **in the direction of motion**.
(D) the downward force of gravity and an upward force exerted on the puck by the table.
(E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

10. **The accompanying diagram depicts a semicircular channel that has been securely attached, in a <u>horizontal plane,</u> to a table top. A ball enters the channel at "1" and exits at "2". Which of the path representations would most nearly correspond to the path of the ball as it exits the channel at "2" and rolls across the table top.**



***Two students, student "a" who has a mass of 77 kg and student "b" who has a mass of 95 kg sit in identical office chairs facing each other. Student "a" places her bare feet on student "b's" knees, as shown below. Student "a" then suddenly pushes outward with her feet, causing both chairs to move.**



"a" "b"

11. In this situation,

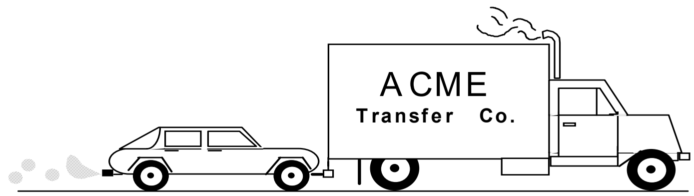
(A) neither student exerts a force on the other.
(B) student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
(C) each student exerts a force on the other but "b" exerts the larger force.
(D) each student exerts a force on the other but "a" exerts the larger force.
(E) each student exerts the same amount of force on the other.

12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

1. *A downward force due to gravity.*
2. *The upward force by the table.*
3. *A net downward force due to air pressure.*
4. *A net upward force due to air pressure.*

(A) 1 only
(B) 1 and 2
(C) 1, 2, and 3
(D) 1, 2, and 4
(E) none of these, since the book is at rest there are no forces acting on it.

* **Refer to the following statement and diagram while answering the next two questions.**



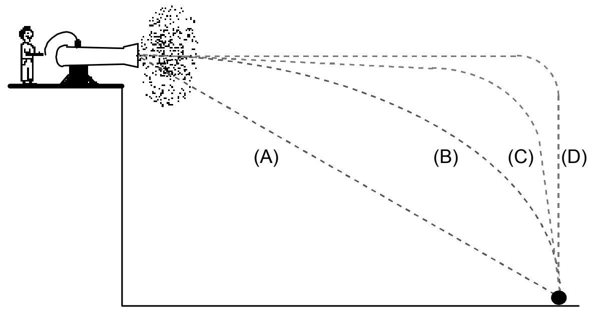
A large truck breaks down out on the road and receives a push back into town by a small compact car.

13. While the car, still pushing the truck, is <u>speeding up</u> to get up to cruising speed;
(A) the force of the car pushing against the truck is equal in amount to that of the truck pushing back against the car.
(B) the force of the car pushing against the truck is less than that of the truck pushing back against the car.
(C) the force of the car pushing against the truck is greater than that of the truck pushing back against the car.
(D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine isn't running so it can't push back with a force against the car.
(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed;
(A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
(B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
(C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
(D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car; the truck is pushed forward simply because it is in the way of the car.
(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because;
(A) energy of the ball is conserved.
(B) momentum of the ball is conserved.
(C) the floor exerts a force on the ball that stops its fall and then drives it upward.
(D) the floor is in the way and the ball has to keep moving.
(E) none of the above.

16. Which of the paths in the diagram below best represents the path of the cannon ball?



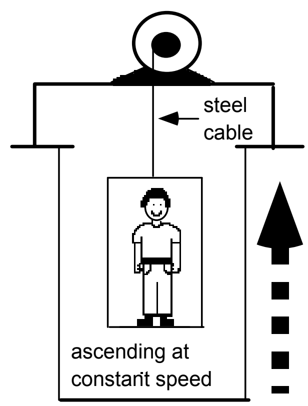
17. A stone falling from the roof of a single story building to the surface of the earth;

(A) reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
(B) speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
(C) speeds up because of the constant gravitational force acting on it.
(D) falls because of the intrinsic tendency of all objects to fall toward the earth.
(E) falls because of a combination of the force of gravity and the air pressure pushing it downward.

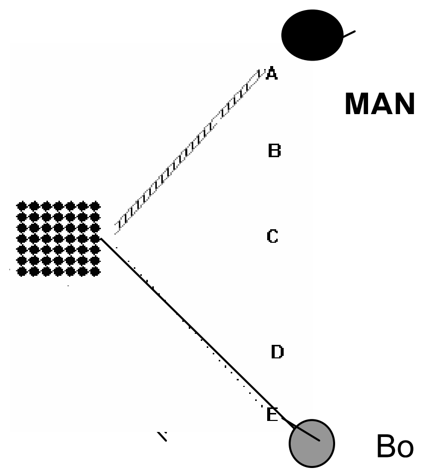
* **When responding to the following question, assume that any <u>frictional forces</u> due to air resistance are so small that they <u>can be ignored.</u>**

18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at a <u>constant velocity.</u>

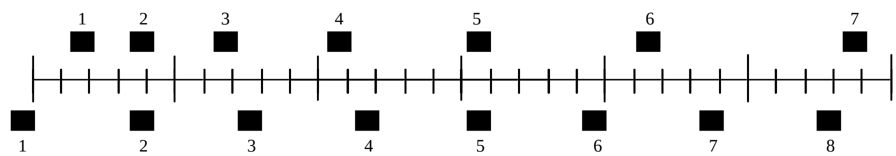
(A) the upward force on the elevator by the cable is greater than the downward force of gravity.
(B) the amount of upward force on the elevator by the cable is equal to that of the downward force of gravity.
(C) the upward force on the elevator by the cable is less than the downward force of gravity.
(D) it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
(E) the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



19. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate, as illustrated in the diagram below. Which of the indicated paths (A-E) would most likely correspond to the path of the crate as they pull it along?

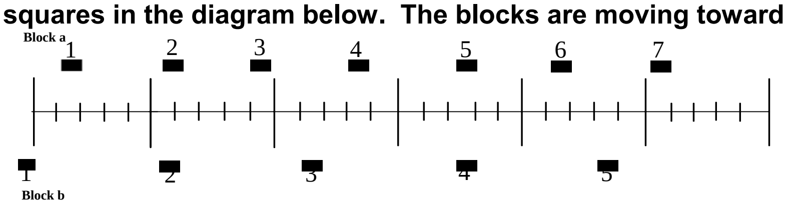


* **The position of two blocks at successive 0.20 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.**



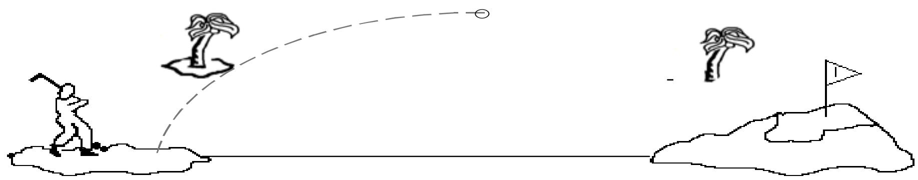
20. Do the blocks ever have the same speed?
- (A) No.
- (B) Yes, at instant 2.
- (C) Yes, at instant 5.
- (D) Yes, at instant 2 and 5.
- (E) Yes, at some time during interval 3 to 4.

* **The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.**



21. The acceleration of the blocks are related as follows:
- (A) acceleration of "a" > acceleration of "b"
- (B) acceleration of "a" = acceleration of "b" > 0
- (C) acceleration of "b" > acceleration of "a"
- (D) acceleration of "a" = acceleration of "b" = 0
- (E) not enough information to answer.

22. After being hit, a golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.

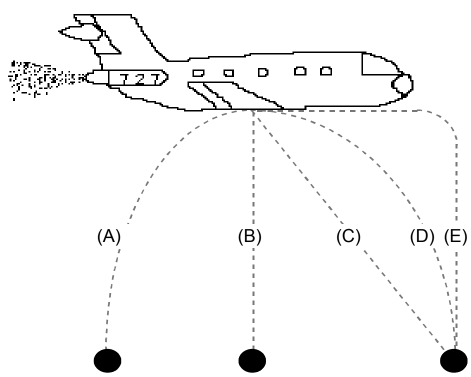


Which following force(s) is(are) acting on the golf ball during its entire flight.

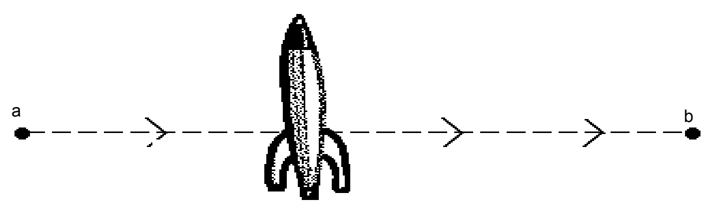
1. *the force of gravity*
2. *the force of the "hit"*
3. *the force of air resistance*

(A) 1 only
(B) 1 and 2
(C) 1, 2, and 3
(D) 1 and 3
(E) 2 and 3

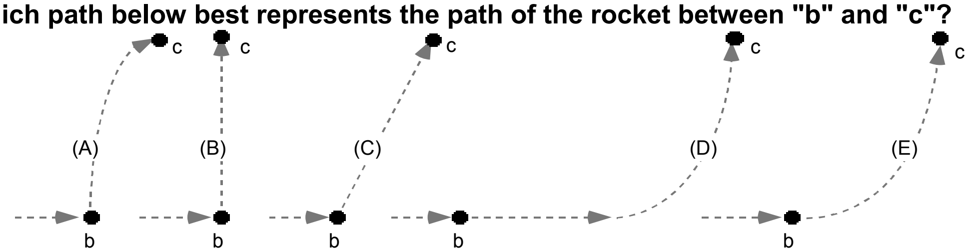
23. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground, which path below would the bowling ball most closely follow after leaving the airplane?



* **When answering the next four questions, refer to the following statement and diagram.**
* **A rocket, drifting sideways in outer space from position "a" to position "b", is subject to no outside forces. At "b", the rocket's engine starts to produce a constant thrust at right angles to line "ab". The engine turns off again as the rocket reaches some point "c".**

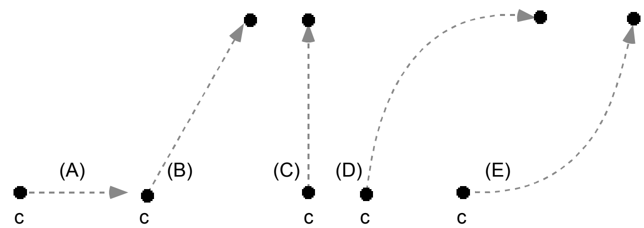


24. Which path below best represents the path of the rocket between "b" and "c"?



25. As the rocket moves from "b" to "c", its <u>speed</u> is;
(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

26. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?



27. Beyond "c", the speed of the rocket is;
(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

28. A large box is being pushed across the floor at a <u>constant speed</u> of 4.0 m/s. What can you conclude about the forces acting on the box?
(A) If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
(B) The force applied to move the box at a constant speed must be more than its weight.
(C) The force applied to move the box at a constant speed must be just equal to the external forces that resist its motion.
(D) The force applied to move the box at a constant speed must be more than the external forces that resist its motion.
(E) There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces, they just resist motion.

29. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will;
(A) stop immediately.
(B) continue at a constant speed for a very short period of time and then slow to stop.
(C) immediately start slowing to a stop.
(D) continue at a constant velocity.
(E) increase its speed for a very short period of time.

APPENDIX D

Elements of a Good Context-rich Problem and its Physics-Specific Strategy (Heller & Heller, 1995; Felder & Brent, 1994)

Writing Good Context-rich Problems for Cooperative Groups

I. Start with an example of a homework problem assigned to the student. Modify the problem. Good group problems are easily made too complex and difficult to solve. A cooperative group problem does **not** have **all** of the characteristics that make a problem more difficult but only one or two. Write the problem like a physics short story. The following steps may be helpful:

1. **Always** focus a context-rich problem on "**You.**" This personalizes the problem and motivates the students.
2. Determine the context (**real objects with real motions** or interactions).
3. Decide on a **motivation** -- Why would anyone want to calculate something in this context?
4. Determine how to write in **the target variable** to make the problem **more** than a one-step exercise.
5. Choose a couple of characteristics that make the problem more difficult, such as:
   a) **Leave out common-knowledge information** (e.g., the value for g) so that students are encouraged to write their given information, goals and assumptions.
   b) W**rite the problem so the solution is not a straight line** nor is it explicitly stated;
   c) Allow for at least two approaches (for example, linear motion and torque) to solve the problem instead of one approach (torque only).

***BEWARE! Check the problem to make sure it is solvable, the physics is straight forward, and the mathematics is reasonable*.**

The Problem Solving Process

II. **Working in Cooperative Groups of 3 students each who** have discussed the *nature of physics* and its impact on problem solving, a suggested five step strategy is given as follows:

- **Focus Your Group:**
  Assume the roles of *Manager, Skeptic* and *Recorder*. **Make assumptions** and write them down, before you start. Break the problem down and design a solution model. Including specific goals and assumptions including physics concepts that might be useful. Simplify the problem situation by sketching it and diagramming the physical objects and object interactions. Discuss each step freely within your group.

- **Discuss and Describe:**
  Use your design of the solution model to set up the path(s) to the solution. Restate what you want to find by naming specific mathematical variables. Write the equation(s) that fit the solution model for how the physical quantities are interrelated, based on your understanding of fundamental physics principles. Discuss each step freely within your group.
- **Derive and Revisit:**
  Derive physics equations that represent the problem mathematically by using the concepts, your sketches and solution model. Estimate a tentative answer, before you go through the effort of actually solving the problem mathematically. Does it make sense at this point? Discuss each step freely within your group.
- **Execute your Plan:**
  During executing the solution, combine your equations you have planned to first determine an algebraic solution, without values. Then plug in all of the known quantities into the algebraic solution to determine a numerical value for the desired unknown (target) quantity(s). Discuss each step freely within your group.
- **Evaluate and Check:**
  Finally, check your work to see that all assumptions, solution model and equations are complete and all steps are given. Is your answer reasonable? Better, did you actually answer the question(s) asked? Discuss each step freely within your group.
  Hints:
  a. Use only one problem sheet per group of 3 students to prevent “parallel processing” and lack of interaction.

Act as a coach or guide. Circulate to help students, answer questions sparingly and with hints rather than answers. Let the students direct the group work, and ask the questions. Just be there to intercede when needed

APPENDIX E

STUDENT SURVEY OF RECITATION FORM BR

Student ID__________________ Physics TA________ Section Number_____________

Location of Recitation ________________________ Date________ Time _______________

RECITATION*	Occurred Often Never Occurred
1. The instructional strategies and activities acknowledged my prior knowledge and learning	**4 3 2 1 0**
2. This lesson was designed to engage me as a member of a larger team of learners.	**4 3 2 1 0**
3. My attempt at solving the problem(s) preceded any formal presentation by the TA.	**4 3 2 1 0**
4. I was encouraged to seek and value several modes of thinking during problem solving	**4 3 2 1 0**
5. This lesson focused on the fundamental concepts rather than on small details.	**4 3 2 1 0**
6. This lesson helped me to understand at a deeper level my understanding of the concepts addressed in lecture and in my homework.	**4 3 2 1 0**
7. My TA had a solid grasp of the content.	**4 3 2 1 0**
8. I was encouraged to use symbolic representations and construct models of the concepts during problem solving.	**4 3 2 1 0**
9. I used a variety of means -- models, drawings, graphs, and concrete materials, to represent phenomena.	**4 3 2 1 0**
10. I made predictions, estimations and sketches during problem solving	**4 3 2 1 0**
11. I was actively engaged in thought provoking activity that often involved the critical assessment of procedures.	**4 3 2 1 0**
12. The problem solving activities helped me to reflect deeply about my own understanding of the material.	**4 3 2 1 0**
13. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	**4 3 2 1 0**
14. I was involved in the communication of my ideas to others during problem	**4 3 2 1 0**
15. The TA's questions triggered me to think from other viewpoints and to other applications of the topics	**4 3 2 1 0**
16. I was engaged in a significant amount of conversation with the TA and other students about topic and content of the problem(s).	**4 3 2 1 0**
17. My questions and those of the other students often determined the focus and direction of classroom conversation.	**4 3 2 1 0**
18. There was a climate of respect for what others had to say	**4 3 2 1 0**

Based on items on the RTOP (MacIsaac & Falconer, 2002).

Comments:

- **The focus and direction of the problem solving activity was:**
- **Examples of connections with real world phenomena and other fields of study that come to mind are**
- **Examples of how I was encouraged to use alternative solution strategies and interpreting evidence during problem solving.**

APPENDIX F

THE MARYLAND PHYSICS EXPECTATIONS SURVEY 2 (MPEX2)

Redish, Saul, & Steinberg, (1998).*

Here are 25 statements (Items 1-25) which may or may not describe your beliefs about this course. You are asked to rate each statement by selecting a response between A and E where the letters mean the following:

A: Strongly Disagree	B: Disagree	C: Neutral	D: Agree	E: Strongly Agree

Answer the questions by filling in the bubble on the Scantron for the letter that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple.
If you do not understand a statement, leave it blank. If you understand, but have no strong opinion one way or the other, choose C. If an item combines two statements and you disagree with either one, choose A or B.
Part I. Space is left after each statement for you to explain your choice and give an example if appropriate.

1. Learning physics will help me understand situations in my everyday life.

2. All I need to do to understand most of the basic ideas in this course is just go to lecture, work most of the problems, read the text, and/or pay close attention in class.

3. The main point of seeing where a formula comes from is to learn that the formula is valid and that it is OK to use it in problems.

4. When learning a new physics topic it's important to think about my personal experiences or ideas and relate them to the topic being analyzed.

5. In this course, adept use of formulas is the main thing needed to solve physics problems effectively.

6. Knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation.

7. If I don't remember a particular equation needed for a problem in an exam I can probably figure out an (ethical!) way to come up with it, given enough time.

8. Physics is related to the real world, but I can understand physics without thinking about that connection.

9. "Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.

---

*Reprinted with the kind permission of the MPEX author, Andrew Elby.

A: Strongly Disagree B: Disagree C: Neutral D: Agree E: Strongly AgreeIn this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens. When doing practice problems for a test or working on homework, if I came up with two different approaches to a problem and they gave different answers, I would not worry about it; after finding out the right answer, I'd just be sure to avoid the incorrect approach.

12. My grade in this course will be primarily determined by how familiar I am with the material. Insight or creativity will have little to do with it.

13. Often, a physics principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in physics is supposed to make sense.

14. If a problem on an exam does not look like one I've already done, I don't think I would have much of a chance of being able to work it out.Tamara just read something in her physics textbook that seems to disagree with her own experiences. But to learn physics well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.

16. The most crucial thing in solving a physics problem is finding the right equation to use.

17. When handing in a physics test, you can generally have a correct sense of how well you did even before talking about it with other students.

18. To really help us learn physics, professors in lecture should show us how to solve lots of problems, instead of spending so much time on concepts, proofs of general equations, and one or two problems

19. A significant problem in this course will be being able to memorize all the information I need to know.

20. Physics professors gave really clear lectures with plenty of real-life examples and sample problems, then most good students could learn those subjects without having to spend a lot of time thinking outside of class.

22. Although physical laws may apply to certain simple situations like we see in class and lab, they have little relation to what I experience in the real world.

Group work in physics is beneficial only if at least one person in the group already understands and knows what they are talking about.

A: Strongly Disagree	B: Disagree	C: Neutral	D: Agree	E: Strongly Agree

23. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the “big ideas” might be helpful for specially-written essay questions, but not for regular physics problems.

24. To understand physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

25. It wouldn’t matter if I didn’t get my homework returned to me as long as I knew which questions I got wrong and I had the solutions to study.

PART II. This section asks for you to make decisions and judgments about the scenarios described.

26. Two students are talking about their experiences in class:

Meena: Our group is really good, I think. We often spend a lot of time confused and sometimes never feel like we have the right answer, but we all listen to each other’s ideas and try to figure things out that way.

Salehah: In our group there is one person who always knows the right answer and so we pretty much follow her lead all the time. This is a great because we always get the tasks done on time and sometimes early.

(a) I agree almost entirely with Meena.
(b) Although I agree more with Meena I think Salehah makes some good points.
(c) I agree (or disagree) equally with Meena and Salehah.
(d) Although I agree more with Salehah, I think Meena makes some good points.
(e) I agree almost entirely with Salehah.

27. In the following question, you will read a short discussion between two students who disagree about some issue. Then you’ll indicate whether you agree with one student or the other.

Tracy: A good physics textbook should show how the material in one chapter relates to the material in other chapters. It shouldn’t treat each topic as a separate “unit,” because they’re not really separate.

Carissa: But most of the time, each chapter is about a different topic, and those different topics don’t always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before choosing one.

(a) I agree almost entirely with Tracy.
(b) Although I agree more with Tracy, I think Carissa makes some good points.
(c) I agree (or disagree) equally with Carissa and Tracy.
(d) Although I agree more with Carissa, I think Tracy makes some good points.
(e) I agree almost entirely with Carissa.

28. Say a student has limited time to study, and therefore must choose between the following options. Assuming the exam will be a fair test of understanding, and assuming time pressure during the exam isn't an issue, which option should the student choose?
    (a) Learning only a few basic formulas, but going into depth with them.
    (b) Learning all the formulas from the relevant chapters, but not going into as much depth.
    (c) Compromising between (a) and (b), but leaning more towards (a).
    (d) Compromising between (a) and (b), but leaning more towards (b).
    (e) Compromising between (a) and (b), midway between those two extremes.

29. Some people have 'photographic memory', the ability to recall essentially everything they read. To what extent would photographic memory give you an advantage when learning physics?
    (a) It would be the most helpful thing that could happen to me
    (b) It would help a lot
    (c) It would help a fair amount
    (d) It would help a little
    (e) It would hardly help at all

30. Consider the following question from a popular textbook:

"A horse is urged to pull a wagon. The horse refuses to try, citing Newton's 3rd law as a defense: The pull of the horse on the wagon is equal but opposite to the pull of the wagon on the horse. 'If I can never exert a greater force on the wagon than it exerts on me, how can I ever start the wagon moving?' asks the horse. How would you reply?"

When studying for a test, what best characterizes your attitude towards studying and answering questions such as this?

(a) Studying these kinds of questions isn't helpful, because they won't be on the test.
(b) Studying these kinds of questions helps a little bit, but not nearly as much studying other things (such as the problem-solving techniques or formulas).
(c) Studying these kinds of questions is fairly helpful, worth a fair amount of time.
(d) Studying these kinds of questions is quite helpful worth quite a lot of my time.
(e) Studying these kinds of questions is extremely helpful, worth a whole lot of my study time.

31. Roy and Theo are working on a homework problem.

Roy: "I remember in the book it said that anything moving in a circle has to have a centripetal acceleration."

Theo: "But if the particle's velocity is constant, how can it be accelerating? That doesn't make sense."

Roy: "Look, right here, under 'Uniform Circular Motion' – here's the equation, $a=v^2/r$. That's what we need for this problem."

Theo: "But I know that to have an acceleration, we need a change in velocity. I don't see how the velocity is changing. That equation doesn't seem right to me."

What would be the advantages (if any) of working with Roy?

____

____

____

What would be the advantages (if any) of working with Theo?

____

____

____

32.) If you could only work with one of them, who do you think would be more helpful?

(a) Roy would be much more helpful.
(b) Roy would be a little more helpful.
(c) They would be equally helpful.
(d) Theo would be a little more helpful.
(e) Theo would be much more helpful.

33.) Several students are talking about group work.

Carmela: "I feel like explaining something to other people in my group really helps me understand it better."

Juanita: "I don't think explaining helps you understand better. It's just that when you can explain something to someone else, then you know you already understood it."

With whom do you agree? Read all the choices before choosing one.

(a) I agree almost entirely with Carmela.
(b) Although I agree more with Carmela, I think Juanita makes some good points.
(c) I agree (or disagree) equally with Juanita and Carmela.
(d) Although I agree more with Juanita, I think Carmela makes some good points.
(e) I agree almost entirely with Juanita.

For the next two questions, please write your answer in the space provided.

Many students report that they sometimes come away from a lecture feeling like they understand a given topic or concept; but when they try to complete a homework problem on that topic, they get stuck. Why do you think this happens?

____
____
____
____
____
____

What, if anything, did you get out of this course that will help you in your chosen profession two years from now?

____
____
____
____
____

34.) Why are you taking this course?
- (a) I'm a biology major (not pre-med). It's required.
- (b) I'm an architecture major. It's required.
- (c) I'm a pre-med. It's required.
- (d) I took it to fulfill some other requirement.
- (e) Other: (please specify): ____

35.) On a scale of 1 to 5, I would rate my overall experience in previous science courses as:
(A) 1: very negative (B) somewhat negative (C) neutral (D) somewhat positive (E) very positive

36.) I feel that my ability to learn physics is:
- (A) well above average in this class (in the top 10% of this class)
- (B) better than average for this class
- (C) about average for this class
- (D) below average for this class
- (E) well below average for this class

37.) Compared to my ability to learn physics, my ability to learn other subjects is:
- (A) much greater
- (B) somewhat greater
- (C) about the same
- (D) somewhat less
- (E) much less

APPENDIX G

RESEARCH QUESTIONS, EVALUATION INSTRUMENT AND RESULTS

RQ	Evaluation Instruments		Results Displayed in Table/Figure:	
	Quantitative	Qualitative		
1	• RTOP		15	16
		• RTOP Comments		
	• Student Survey			17
		• Student Survey Comments	35, 36	
	• Final Course Grades		29	35
2	• MPEX2 Part I			18
		• MPEX2, Part II	37	20
	• GTA Interviews /RTOP Correlations			19, 32
		• Interview Comments	20, 21	
		• RTOP Comments	19	
		• Diagnoser		22
3	• DFA		24	
		• Video Analysis	39	
			32, 33	
	• FCI Pre/post			23
		• FM2CA	30	26
	• Cohen's d			24
		• CPQs		
		• Traditional Problem**		
	• Hake Gain (g)		28	25
	• Cooperative Group Interaction Analysis			29
	• FCI change			34

*Treatment Group Only
**Control Group Only

VITA

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Educational Background

Doctor of Philosophy	Texas A&M University, C & I/Science Education	2004
Master of Science	University of Houston, C & I/Physics Education	1988
Bachelor of Science	Ashland University, Geology/Natural Science	1977

Professional Experience

2001-2004	Graduate Research Assistant, ITS and Physics, Texas A&M.
2001-present	Pre-College Editor, ThePhysicsFront.org; comPADRE, AAPT
2000-2002	Dept. Head, Academy for Science & Health Professions, Conroe, Texas
1995-2002	Instructor, Introductory Physics 1401, 1402, Montgomery College/Kingwood College Science Department Head Oak Ridge High School, Conroe TX Teacher, AP B, C and Honors Physics, Geology, Laboratory Research and Design, Oak Ridge High School, Conroe ISD
1993 - 2001	Field Adjunct, Texas Education Agency – TEKS Frameworks Teacher, Honors Physics, General Chemistry, Astronomy, Geology, Laboratory Research and Design, McCullough High School, Conroe ISD
1984 -1992	Assistant Department Head, Clements High School, Fort Bend ISD Teacher, AP B, C and Honors Physics, Geology, Laboratory Research and Design, Integrated Physics and Chemistry, Clements High School, Fort Bend ISD

Publications

Refereed Papers/Books

Ezrailson, C. M., Allen G. D. & Loving C. C. (June, 2004). Analyzing dynamic pendulum motion in an interactive online environment using Flash. *Science & Education*, *4*(4), Dordrecht: Kluwer.

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Biggs, A., Burns J., Daniel, L. H., Ezrailson, C.M., Feather, R. M., Horton P. M., McCarthy, T. K., Ortleb, E., Snyder, S. L. & Werwa, E. (2000). *Science Voyages*: *An Exploration of the Life, Earth, and Physical Sciences*, New York: Glencoe/McGraw-Hill.